BIONOMICS OF SLASH PINE FLOWER THRIPS, *Gnophothrips fuscus* (MORGAN), IN PINE SEED ORCHARDS OF FLORIDA

BY

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TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS.. ii

LIST OF TABLES... viii

LIST OF FIGURES.. x

ABSTRACT... xii

CHAPTER

I INTRODUCTION.................................. 1

II REPRODUCTION AND POLYMORPHISM................ 6

- Introduction.............................. 6
- Materials and Methods..................... 6
  - Mating and Oviposition Behavior......... 6
  - Sex Ratio and Polymorphism.............. 7
- Results and Discussion.................... 7
  - Mating and Oviposition Behavior......... 7
  - Sex Ratio and Polymorphism.............. 8
- Summary................................... 9

III DESCRIPTIONS OF IMMATURE STAGES............. 10

- Introduction.............................. 10
- Materials and Methods..................... 10
- Descriptions of Immature Stages........... 12
  - Egg..................................... 12
  - Stage I larva........................... 12
  - Stage II larva.......................... 15
  - Prepupa................................. 18
  - Stage I pupa............................ 18
  - Stage II pupa........................... 19
- Identification of Immature Stages......... 20
  - Key to larvae, prepupa and pupae........ 20
- Summary................................... 21

CHAPTER Page

IV OCCURRENCE, DEVELOPMENT AND BEHAVIOR OF IMMATURE STAGES.................... 30

Introduction.......................... 30
Materials and Methods................. 30
Sampling of Soil.................... 30
Sampling of Bark.................... 31
Sampling of Shoots.................. 31
Laboratory Rearing.................. 32
Results and Discussion................ 33
Occurrence of Immature Stages........ 33
Development of Immature Stages....... 35
Behavior of Larvae, Prepupa and Pupae 37
Summary............................... 37

V LIFE HISTORY AND SEASONAL ABUNDANCE OF LIFE STAGES ON SLASH PINE.............. 39

Introduction.......................... 39
Materials and Methods................. 40
Young Slash Pines................... 40
Mature Slash Pines.................. 40
Results............................... 41
Young Slash Pines................... 41
Mature Slash Pines.................. 44
Discussion............................ 46
Young Slash Pines................... 46
Mature Slash Pines.................. 50
Summary............................... 51

VI SEASONAL ABUNDANCE OF ADULTS FLYING WITHIN CROWNS OF SLASH PINES IN A SEED PRODUCTION AREA........................ 52

Introduction.......................... 52
Materials and Methods................. 53
Results and Discussion................ 54
Summary............................... 58

VII VERTICAL DISTRIBUTION OF ADULTS FLYING IN A SLASH PINE SEED ORCHARD.............. 60

Introduction.......................... 60
Materials and Methods................. 60
Results and Discussion................ 64
Summary............................... 67

VIII DAMAGE TO SLASH PINE..................... 68

Introduction.......................... 68

CHAPTER Page

Materials and Methods.................. 72
  Damage to Foliage.................... 72
  Relation of _G. fuscus_ Attacks to Chronology of Conelet Development. 73
  Induction of _G. fuscus_ Damage in Female Strobili.................. 74
  Relation Between _G. fuscus_ Damage and Conelet Mortality................. 76
  Damage by _G. fuscus_ to Sporophyll Tissues............................ 76
Results and Discussion................. 77
  Damage to Foliage.................... 77
  Relation of _G. fuscus_ Attacks to Chronology of Conelet Development. 78
  Induction of _G. fuscus_ Damage in Female Strobili.................. 79
  Relation Between _G. fuscus_ Damage and Conelet Mortality................. 79
  Damage by _G. fuscus_ to Sporophyll Tissues............................ 80
Summary................................ 80

IX ASSOCIATION WITH PITCH CANKER FUNGUS..... 83

Introduction........................... 83
Materials and Methods.................. 84
  Incidence of FMS on _G. fuscus_ Adults Collected from Slash Pines in a Pitch-cankered Plantation......... 84
  Gnophothrips fuscus Feeding Wounds on Slash Pine Conelets as Infection Courts for FMS.................... 86
Results and Discussion................. 89
  Incidence of FMS on _G. fuscus_ Adults Collected from Slash Pines in a Pitch-cankered Plantation......... 89
  Gnophothrips fuscus Feeding Wounds on Slash Pine Conelets as Infection Courts for FMS.................... 90
Summary................................ 92

X INSECTICIDAL CONTROL OF THRIPS DAMAGE TO SLASH PINE CONELETS.................... 93

Introduction........................... 93
Insecticide Treatment of the Bark...... 93
  Introduction......................... 93
  Materials and Methods................ 94
  Results and Discussion............... 95

CHAPTER Page

Interaction between Early Vs. Late Winter Spraying of an Insecticide and Early Vs. Late Flowering in Slash Pine.................................. 96
  Introduction.......................... 96
  Materials and Methods.................. 99
  Results and Discussion................ 101
Summary.................................. 101

XI SUMMARY AND CONCLUSIONS.................... 103

APPENDICES

A DEVELOPMENTAL STAGES OF PINE FEMALE STROBILI FROM BUD-BREAK TO POLLINATION....... 106

B PROCEDURE TO PREPARE SLASH PINE FEMALE SPOROPHYLLS FOR SECTIONING............... 108

C SAFRANIN-FAST GREEN STAINING SERIES........ 110

D DERIVATION OF THE STATISTICAL MODEL........ 112

E SELECTIVE MEDIUM FOR *Fusarium moniliforme* var. *subglutinans*........................ 114

LITERATURE CITED.................................. 115

BIOGRAPHICAL SKETCH................................ 121

LIST OF TABLES

Table Page

1. Duration of immature stages of Gnophothrips fuscus laboratory-reared at 22±1°C and 12D:12L photoperiod........................ 35

2. The number of Gnophothrips fuscus collected by beating 2 vegetative shoots per quadrant from 6 cone-bearing slash pines growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL............................ 45

3. Number of Gnophothrips fuscus adults caught on sticky traps hung at 4 different heights among slash pines growing at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL....... 66

4. The number and percent of G. fuscus adults and paper points (controls) contaminated with pitch canker fungus at Norfleet Slash Pine Plantation located in Gilchrist County, FL................................ 89

5. The initial number and mortality of conelets, and the number of conelets from which Fusarium moniliforme var. subglutinans (FMS) was re-isolated in an experiment to find whether feeding wounds of Gnophothrips fuscus adults can be infection courts to FMS in slash pine clone 74/61 grown at the University of Florida Clonal Pine Bank located in Alachua County, FL................ 90

6. Mortality of Gnophothrips fuscus-damaged conelets in ramets with lindane-sprayed bark and in unsprayed ramets belonging to 5 slash pine clones growing at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL....... 97

Table | Page

7. Number of *Gnophothrips fuscus* adults caught on sticky traps hung in the upper southeast quadrant of ramets with lindane-sprayed bark and in unsprayed remets belonging to 5 slash pine clones grown at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL........... 98

8. The percent of *Gnophothrips fuscus*-damaged and *G. fuscus*-killed conelets in malathion-sprayed ramets and in unsprayed controls belonging to 2 early-flowering and 2 late-flowering slash pine clones growing at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL................................ 102

LIST OF FIGURES

Figure Page

1. Dorsal view of a macropterous adult female, Gnophothrips fuscus 3

2. Lateral view of the egg, Gnophothrips fuscus. 22

3. Polygonal areas with openings in reticulate sculpturing of the egg, Gnophothrips fuscus.. 22

4. Stage I larva, Gnophothrips fuscus........... 23

5. Stage II larva, Gnophothrips fuscus.......... 24

6. Prepupa, Gnophothrips fuscus................. 25

7. Stage I pupa, Gnophothrips fuscus............ 26

8. Stage II pupa, Gnophothrips fuscus........... 27

9. Dorsal view of right antenna of stage I larva, Gnophothrips fuscus................... 28

10. Dorsal view of right antenna of stage II larva, Gnophothrips fuscus................... 28

11. Dorsal view of the abdominal segments IX-X of stage I larva, Gnophothrips fuscus........ 29

12. Dorsal view of the abdominal segments IX-X of stage II larva, Gnophothrips fuscus....... 29

13. Seasonal abundance of Gnophothrips fuscus life stages on shoots of young slash pines growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL................. 43

14. Observed and estimated occurrence of Gnophothrips fuscus life stages on shoots of young slash pines growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL..... 49

Figure Page

15. Activities of _Gnophothrips fuscus_ adults, mean monthly averages of maximum and minimum temperatures and mean monthly catches of _Gnophothrips fuscus_ adults per trap in 24 sticky traps hung in the crowns of 6 slash pine seed trees growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL.... 56

16. Arrangement of sticky traps used to study the vertical distribution of _Gnophothrips fuscus_ flying among slash pines at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL 63

17. Relationship between the number of _Gnophothrips fuscus_ adults caught per trap and the height level of the trap above ground at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL........................... 65

18. Chronology of slash pine female strobili development in Florida........................ 70

19. Longitudinal section of a slash pine female sporophyll.................................... 81

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BIONOMICS OF SLASH PINE FLOWER THRIPS, *Gnophothrips fuscus* (MORGAN), IN PINE SEED ORCHARDS OF FLORIDA

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Chairman: R. C. Wilkinson
Major Department: Entomology and Nematology

Bionomics of *Gnophothrips fuscus* (Morgan) (Thysanoptera: Phlaeothripidae) on slash pine, *Pinus elliottii* Engelm. var. *elliottii*, was studied from December 1977 through June 1980 in northeastern Florida.

Gnophothrips fuscus adults are polymorphic and had a ♂:♀ sex ratio of 1: 3. The egg has a sculptured chorion. The other immature stages differ from one another in the structure of their antennae and chaetotaxy. At 22±1°C this thrips developed from egg to adult in ca. 46 days.

During spring and summer an estimated 3 overlapping generations of *G. fuscus* developed on rapidly elongating vegetative shoots of young slash pines. Their feeding damage on growing needles of slash pine appeared as pale yellowish-white patches. The adults fed upon young conelets during winter and caused histological degeneration in sporophyll tissues. In dead conelets with thrips damage, an average 7% of the scales were thrips-attacked.

The number of *G. fuscus* adults caught on sticky traps placed within the crowns of slash pine seed trees was lowest during winter, reached a peak during spring and gradually declined through summer and fall. More thrips were caught at heights corresponding to the mid- and upper crown levels of cone-bearing slash pines than at lower crown and bole levels.

Incidence of pitch canker fungus, *Fusarium moniliforme* Sheld. var. *subglutinans* Wollenw. and Reink, was low on *G. fuscus* adults collected from a pitch-cankered slash pine plantation. The number of dead conelets from which pitch canker fungus was re-isolated, did not differ significantly between slash pine conelets exposed to thrips and sprayed with an inoculum of the fungus and distilled water sprayed controls.

An early winter spray of lindane to the bark of cone-bearing slash pines significantly reduced thrips damage to conelets. There was no significant interaction between early vs. late flowering in 4 slash pine clones and early vs. late winter application of malathion, in reference to thrips-caused mortality to conelets.

CHAPTER I
INTRODUCTION

Slash pine, Pinus elliottii Engelm. var. elliottii, is an economically important tree species in the southeastern USA. The natural range of this pine is limited to the coastal and Piedmont areas from southeastern South Carolina to southeastern Louisiana and south through Florida. Slash pine plantations are found in an extended range from southeastern North Carolina to eastern Texas (Boyce et al. 1975). There are ca. 5 million ha of slash pine in the U. S. (Langodon and Bennett 1976); of these 2.1 million ha are located in Florida (Conde and Rockwood 1979). Slash pine has been the most commonly planted pine species in its range (Dorman 1976).

The widespread desire for select slash pine seedlings has resulted in the establishment of numerous seed orchards in the southeastern USA. There are ca. 1300 ha of slash pine seed orchards in this region; ca. 50% of this seed orchard area is located in Florida (R. E. Goddard, personal communication 1981). In 1979, ca. 89 million slash pine seedlings were produced in forest nurseries of Florida (Barnard 1980). In view of the increasing demand for quality seeds, intensive management is necessary to maximize the yield of slash pine seed orchards.

Insect pests and diseases are major limiting factors of quality seed production in slash pine seed orchards. In the absence of pest management these may reduce the potential yield of sound seeds in slash pines by 88% (Fatzinger and Miller 1980). Coneworms, flower thrips and seedbugs are among the serious pests in these seed orchards (Hedlin _et al_.1980, Merkel 1974, Schmidt and Wilkinson 1979).

The adults of slash pine flower thrips, _Gnophothrips fuscus_ (Morgan), (Figure 1) feed on the developing female strobili[1] (DeBarr 1969, Ebel 1961). This feeding damage may kill up to 46% of the strobilus crop (DeBarr 1969). Nonlethal damage by thrips caused development of distorted, significantly shorter cones with fewer filled seeds than in those cones developed from undamaged strobili (DeBarr and Williams 1971).

The genus _Gnophothrips_ was erected by Hood and Williams (1915) who described the new species _G. megaceps_. Crawford (1938) described _G. piniphilus_ from nursery stock of Austrian pine, _Pinus nigra_ Arnold. O'Neill (1965) synonymized _Trichothrips fuscus_ Morgan (Morgan 1913), _Liothrips fuscus_ (Morgan) (Hood 1918) and _G. piniphilus_ Crawford (Crawford 1938) under _G. fuscus_. Stannard (1968) synonymized _G. megaceps_ with _G. fuscus_. The genus _Gnophothrips_ remains monotypic at present.

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[1] Strobili are reproductive structures of pines.

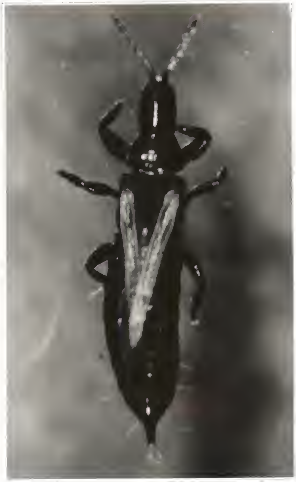

Figure 1. Dorsal view of a macropterous adult female, Gnophothrips fuscus (length 1.86 mm).

The known geographical distribution of _G_. _fuscus_ ranges from the southern U. S. to southern and western Canada. In the U. S. these thrips have been collected from Florida (Morgan 1913), South Carolina (Ciesla and Franklin 1965), New York (Crawford 1938), Rhode Island (Crawford 1938), Virginia and from Massachusetts (O'Neill 1965). In Canada this insect has been found in Ontario (Lindquist and Harnden 1957) and in Alberta (Powell 1971).

The biology of this thrips was little known when this study was initiated. There were no detailed descriptions of its immature stages. The life history of this insect was only partially known (Ebel _et_ _al_. 1975). The feeding damage done by this insect has not been studied. There was little knowledge about the seasonal abundance of this thrips. Although these thrips have been consistently collected from pitch-cankered slash pine plantations in Florida (R. C. Wilkinson, personal communication, 1977), the incidence of pitch canker fungus, _Fusarium_ _moniliforme_ Sheld. var. _subglutinans_ Wollenw. and Reink., (FMS) on _G_. _fuscus_ had never been determined.

The objectives of this research were to:

1. Describe the life stages and the life cycle of _G_. _fuscus_ in northeastern Florida.
2. Investigate the feeding damage done by this insect.
3. Determine the seasonal abundance and movement of _G_. _fuscus_ among slash pine seed trees in northeastern Florida.

4. Determine the incidence of pitch canker fungus on *G. fuscus* adults flying in pitch-cankered slash pine plantations in northeastern Florida and to find whether their feeding wounds on female strobili can be infection courts for the fungus.
5. Study insecticidal control methods of *G. fuscus* in slash pine seed orchards.

CHAPTER II
REPRODUCTION AND POLYMORPHISM

Introduction

The details of *G. fuscus* mating behavior, oviposition and sex ratio have never been reported. In Tubulifera the females have a short internal rod (fustis) lying just forward of the base of the tube; the male tubuliferans lack this structure and have the central portion of the basal sternal margin of the tube incised (Stannard 1968). The males of *G. fuscus* are smaller than the females. The adults of this insect are polymorphic (Crawford 1938, Hood and Williams 1915, Lindquist and Harnden 1957, Stannard 1968).

The mating and oviposition behavior, sex ratio and polymorphism of *G. fuscus* are reported here.

Materials and Methods

Mating and Oviposition Behavior

The adults of *G. fuscus* were observed on young slash pines growing in the field to determine their mating and oviposition behavior. In the laboratory field-collected and laboratory-reared adults were observed on vegetative shoots similar to those on which G. fuscus were reared (see page 32).

Sex Ratio and Polymorphism

Gnophothrips fuscus adults were collected from several localities in Alachua, Baker, Columbia and Gilchrist Counties in FL. Some of these adults were collected year-round by beating vegetative shoots. A 30-cm terminal section of the shoot was beaten for ca. 30 sec onto a beating-lid, i.e., a garbage can cover painted white to facilitate locating the thrips. Other G. fuscus adults were hand-picked from shoots examined under a dissecting microscope, using a camel hair brush. Adults were also trapped using yellow plastic discs (15 cm diam) coated on one side with Tanglefoot® insect adhesive and hung within crowns of slash pine seed trees. The characters described by Stannard (1968) were used to determine the sex of these adults. The wing type of the adults was found by observing the adults under a dissecting microscope.

Results and Discussion

Mating and Oviposition Behavior

Mating behavior was observed in the laboratory only. First the male and the female felt each other with their antennae for ca. 5 sec. The male then grasped the female with his fore-legs and mounted on her. The tube of the male was curved under that of the female. Sometimes the female moved with the male on her back, while they were still in union. The copulation took an average of 55 sec. This mating behavior is similar to that of other Tubulifera (Lewis 1973, Stannard 1968). The touching of the antennae prior to mounting is a behavior pattern by which the sexes of the same thrips species find each other by using the sense cones located in the antennae (Lewis 1973). These observations suggest that G. fuscus undergo sexual reproduction. Among some species of thrips males are rare or unknown and their reproduction is by female to female parthenogenesis (Lewis 1973).

Oviposition by this thrips was not observed. The laboratory-reared females failed to oviposit. However, 27 females field-collected and kept in the laboratory laid an average of 4.1 eggs per female (range 2-8). This is a low oviposition rate because thrips in general have an egg-laying capacity of 25-30 eggs per female (Ananthakrishnan 1979). The low rate of fecundity observed may be due to these adults having already laid some eggs in the field. It is also possible that cut-shoots offered to these adults provided them with a poor quality diet which lowered their fecundity.

Sex Ratio and Polymorphism

The adults of G. fuscus collected had a sex ratio (♂:♀) of 1:3. There were 63 males and 190 females. The sex ratios of the adults collected by beating (9:28), hand-picking (38:104) and trapping (16:58) did not differ significantly ($X^2 = 0.56$ NS with 2 df). This predominance of females is common among thrips (Lewis 1973). The above sex ratio suggests that G. fuscus undergoes sexual reproduction.

The adults are polymorphic with 63% (96) brachypterous (short-winged), 30% (46) macropterous and 7% (11) apterous morphs in a sample of 153. The predominance of brachypterous form among G. fuscus is common (Crawford 1938, Lindquist and Harnden 1957). Out of 50 males in the sample, 84% (42) were brachypterous, 12% (6) were macropterous and 4% (2) were apterous. Among 103 females in this sample, 53% (54) were brachypterous, 39% (40) were macropterous and 8% (9) were apterous. The brachyptery can either be due to food quality (Lewis 1973) or photoperiod (Ananthakrishnan 1979). All the adults captured on the traps were macropterous. This suggests that long-winged morphs are the principal dispersing form.

Summary

The laboratory-observed copulation of G. fuscus took ca. 55 sec and was similar to that reported on other Tubulifera. The oviposition was not observed. The fecundity rate of adults kept in the laboratory was lower than the average reported for other thrips. The sex ratio of adults was 1:3. Although the brachypterous form was predominant, the adults caught on sticky traps were all macropterous. Few of the adults were apterous.

CHAPTER III
DESCRIPTIONS OF IMMATURE STAGES

Introduction

The morphological details of *G. fuscus* adults are reported by Crawford (1938), Hood and Williams (1915), Morgan (1913) and Stannard (1968). The immature stages of *Gnophothrips* spp. are orange-yellow (Wilson 1977). The external morphological details of *G. fuscus* immature stages are described here for the first time. The pattern of sculpturing on the egg is shown because it may be diagnostic for the species. The structures of the larvae are described in greater detail than that of the other developmental stages because the stage II larva is considered the most "taxonomically stable" immature stage of a thrips (Ananthakrishnan 1979, Vance 1974); the larvae are also the most commonly encountered immature stages of this insect in the field. A key to larvae, prepupa and pupae of *G. fuscus* is also presented.

Materials and Methods

Field-collected and laboratory-reared eggs were transferred onto moistened filter papers placed in Petri dishes to obtain the larvae. These larvae were reared in the laboratory on 15-cm-long, insect-free terminal shoots of the current vegetative growth of young slash pines; each such shoot was waxed at the base and kept individually in a 36-oz Whirl-pak® polyethylene bag (also see page 32 for details). The prepupae were transferred into Petri dishes containing moistened filter papers and kept there until the emergence of the adults. All rearings were done at 12L:12D photoperiod.

The eggs were examined using light and scanning electron microscopy[1] to describe the surface of the chorion. The specimens of other immature stages were prepared for light microscopy (Olympus® BH-1 binocular microscope) by using the technique outlined by Vance (1974). All measurements were made with a pre-calibrated optical micrometer. The classification by Speyer and Parr (1941) was used to characterize the setae. All the other terminology is based on Lewis (1973). The illustrations, except those of the eggs, were made from the photomicrographs of the mounted specimens. At least 5 specimens from each of the larval and pupal stages were examined; only 3 prepupae were observed in detail, however.

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[1] Courtesy of T. C. Carlysle of the USDA Insect Attractants, Behavior, and Basic Biology Research Laboratory, Gainesville, FL

Description of Immature Stages

Egg

Newly-deposited egg light amber becoming darker amber with development; shiny or matte, ovoid (Figure 2). Length 0.38-0.55 mm ($\overline{x}$±SD = 0.51±0.04 mm), width 0.13-0.20 mm ($\overline{x}$±SD = 0.18±0.02 mm, N = 38) . Egg chorion with reticulate sculpturing at the narrower end. Under scanning electron microscopy sculpturing appeared to consist of polygonal areas each perforated by several openings (Figure 3).

Stage I Larva

Larva pale yellow at emergence becoming darker yellow at maturity. Body length 0.59-1.19 mm ($\overline{x}$±SD = 0.85±0.18 mm, N = 38) for larvae of both sexes.

In mature stage I larva, head pale yellow and as long as wide dorsally (Figure 4). Eyes brownish-red, bulging slightly. Ocelli absent. Cheeks diverging posteriorly with no constrictions. Seven-segmented antennae at the anterior lateral margin of the head, directed forwards. First antennal segment pale yellow; segments 2-3 pale black in the basal 2/3 and pale yellow in the terminal 1/3; segments 5-7 brown. In dorsal view (Figure 9) first antennal segment broader than long; segments 2-5 claviform with segment 3 slightly shorter than segment 4; segment 6 trapezoidal and segment 7 cone-shaped.

Prothorax trapezoidal and ca. 1.5X as wide as the head dorsally (Figure 4). Meso- and metathorax more or less cylindrical, about equal in width. Wing buds absent. Legs similar, each with a pair of hooks on tarsi. Pro- and mesothoracic coxae ca. equidistant, but metathoracic coxae closer together than others. A pair of spiracles on mesothorax.

Abdomen 11 segmented, tapered gradually till segment VIII and then narrowing sharply in segments IX-X; segment X tubuliform. Abdominal spiracles in segments II and VIII. A pair of pori in segments IX and X (Figures 4, 11). Locally sclerotized areas present around the bases of some dorsal crateriform setae, particularly those located near the mid-dorsal line.

Chaetotaxy. Setal arrangement bilaterally symmetrical (Figure 4).

First antennal segment with an acute seta inner lateral (Figures 4, 9); segment 2 with 2 crateriform setae and a circular sensorium dorsal, 1 blunt seta inner lateral and 2 blunt setae ventral; segment 3 with a blunt seta and a crateriform seta dorsal, a blunt seta inner lateral and 2 blunt setae ventral. Only blunt setae on the remaining antennal segments. Segment 4 with 2 setae dorsal and 1 seta ventral; segment 5 with 1 seta lateral on either side, 1 seta ventral; segment 6 with 1 seta inner lateral and 2 setae ventral; segment 7 with 3 setae dorsolateral, 2 setae ventral and 1 seta terminal. Sense cones (relatively thin-walled conical sensoria), 2 on antennal segment 4 and 1 on segments 3, 5 and 6. The rest of the head with 1 pair of post-ocular acute setae and 3 pairs of crateriform setae dorsal, 2 pairs of acute setae ventral (Figure 4). Setae on mouth parts not counted.

Prothorax with 4 pairs of crateriform setae and 2 pairs of acute setae dorsal, none ventral (Figure 4). Mesothorax with 3 pairs of crateriform setae and 4 pairs of acute setae dorsal, 1 pair of acute setae ventral. Metathorax with 3 pairs of crateriform setae dorsal and a pair of acute setae lateral, none ventral. Setae on legs not included.

Abdominal segment I with 2 pairs of crateriform setae and a pair of acute setae dorsal, none ventral; segment II with 3 pairs of crateriform setae dorsal in a transverse row, 1 pair of acute setae ventral; segment III-VII with 2 pairs of crateriform setae dorsal, 1 pair of crateriform setae dorso-lateral and 2 pairs of acute setae ventral. The dorso-lateral setae gradually increased in length towards the posterior segments. The outer pair of ventral acute setae in these segments comparatively smaller than the inner pair. Abdominal segment VIII with 2 pairs of crateriform setae dorsal and 2 pairs of subequal acute setae ventral; segment IX with 2 pairs of crateriform setae dorsal with the outer pair ca. 1.5X as long as the inner pair (Figures 4, 11), 1 pair of acute setae ventral; segment X with 1 pair of acute setae dorsal and ventral ca. the middle of the segment and 4 pairs of setae terminal i.e. 2 pairs of acute setae dorsal, 1 pair of acute setae and a pair of flagelliform setae ventral.

Stage II Larva

Yellow to brownish-yellow. Body length 0.79-2.08 mm ($\bar{x}$±SD = 1.37±0.30 mm, N = 31). for larvae of both sexes.

In mature stage II larva, head comparatively lighter yellow than thorax and abdomen, oblong ventrally (Figure 5). Eyes dark brown with no apparent bulging. Ocelli absent. Cheeks with no constrictions. Antennae at the anterio-lateral margin of the head and directed forwards. All the antennal segments brownish-yellow except the terminal pale black segment. Antennal segment 1 broader than long (Figure 10); segment 2 more or less cylindrical; segments 3-5 claviform with segment 3 ca. 1.8X as long as segment 4; segment 6 rectangular and segment 7 cone-shaped. Mouth cone well-developed extending almost to the posterior margin of the presternum (Figure 5); base of the maxilla reaching the level of the eyes and the maxillary stylets touching each other when withdrawn; mandible with left stylet only; maxillary and labial palps 2-segmented.

Thorax dark yellow. Prothorax trapezoidal and ca. 2X as wide as the head. Meso- and metathorax more or less cylindrical, ca. equal in width. Wing buds absent. Legs similar; pro- and mesothoracic coxae ca. equidistant, metathoracic coxae closer together than others; legs each with a pair of hooks on the tarsi. Pair of spiracles on mesothorax, dimensions average 90 x 60 microns. Sclerotized areas dorsally on meso- and metathorax. Sclerotization around the bases of dorsal crateriform setae on meso- and metathorax.

Abdomen 11 segmented, brownish-yellow. Abdominal segments I-IV ca. equal in width. Gradual decrease in size from segments V-VIII and then a sharp reduction to end up in tubuliform segment X; segment XI withdrawn into X. Spiracles on segments II and VIII, dimensions average 50 x 30 microns. Pair of pori dorsally on abdominal segments VIII-X. Sclerotized areas around the bases of dorsal crateriform setae on segments I-VII. Roughly triangular glandular areas extending from the lateral margin towards the mid-line on segment VIII.

Chaetotaxy. Setal arrangement bilaterally symmetrical (Figure 5). Within each segment setae are numbered sequentially from posterior to anterior and from center towards periphery. Minor setae and setae on appendages not numbered.

Antennal segment 1 with an acute seta inner lateral (Figures 5, 10); segment 2 with 2 crateriform setae and a circular sensorium dorsal, 1 blunt seta inner lateral and 2 blunt setae ventral; segment 3 with a crateriform seta dorsal, 2 blunt setae ventral. Setae on the remaining antennal segments are of blunt type. Segment 4 with 1 seta dorsal, 1 seta outer lateral and 1 seta ventral; segment 5 with 1 seta lateral on either side, 1 seta ventral; segment 6 with 1 seta dorsal, 1 seta inner lateral and 1 seta ventral; segment 7 with 3 setae dorso-lateral, 2 setae ventral and 1 seta terminal. Two sense cones on segments 3 and 4, one on segments 5 and 6. The rest of the head with 4 pairs of setae dorsal, all but pair no. 3 of blunt setae are crateriform (Figure 5); 3 pairs of acute setae ventral (2 pairs on labial region not counted).

Prothorax with 6 pairs of crateriform setae dorsal and 3 pairs of acute setae ventral. Mesothorax with 6 pairs of crateriform setae dorsal in 2 transverse rows of 3 pairs, 4 pairs of acute setae and a pair of minor acute setae ventral. Metathorax with 6 pairs of crateriform setae dorsal in 2 transverse rows of 3 pairs, 1 pair of acute setae and a pair of minor acute setae ventral.

Abdominal segment I with 2 pairs of crateriform setae and 2 pairs of minor acute setae dorsal, none ventral; segment II with 3 pairs of crateriform setae dorsal in a transverse row, 1 pair of acute setae and a pair of minor acute setae ventral; segments III-VII with 3 pairs of crateriform setae dorsal in a transverse row; segments III-V with an inner pair of acute setae and an outer pair of blunt setae ventral; segments VI-VII each with 2 pairs of acute setae ventral; segment VIII with 2 pairs of crateriform setae dorsal, 2 pairs of acute setae and a pair of crateriform setae ventral; segment IX with 2 subequal pairs of crateriform setae dorsal (Figure 12), an inner pair of acute setae and an outer pair of crateriform setae ventral; segment X with an acute pair of setae dorsal and ventral at ca. the middle of the segment and 5 pairs of terminal setae i.e. 3 pairs of acute setae dorsal, 1 pair of acute setae and a pair of flagelliform setae ventral.

Prepupa

Yellow to dark yellow. Body length 1.29-1.68 mm ($\bar{x}$±SD = 1.50±0.16 mm, N = 6) for prepupae of both sexes.

Head with yellow pigment lighter around the mid-dorsal area. Antennae light yellow, stubby and directed laterad (Figure 6). Eyes reddish-brown. Mouth parts not apparent.

Prothorax light yellow. Meso- and metathorax dark yellow. Wing buds absent. Legs similar with tarsi lighter yellow than the rest of the leg. Pair of hooks on the tarsus. One pair of mesothoracic spiracles.

Abdomen dark yellow except for the light yellow tube. Neither spiracles nor pori visible.

All setae except the terminal acuminate seta on the tube are of acute type. Chaetotaxy is shown in Figure 6.

Stage I Pupa

Yellow to dark yellow. Body length 1.49-1.63 mm ($\bar{x}$±SD = 1.56±0.07 mm, N = 6) for stage I pupae of both sexes.

Head with yellow pigment distributed unevenly. Antennae translucent and attached to the lateral margin of the head (Figure 7). Antennae do not extend beyond the anterior margin of the pronotum. Eyes reddish-brown and ca. 1/4 as long as the head dorsally. Ocelli absent. Mouth parts not apparent.

Thorax yellow except for the colorless wing buds. Mesothoracic wing buds reaching the anterior end and the metathoracic wing buds extending to the posterior end of the first abdominal segment. Legs pale yellow except for the translucent tarsi. A pair of spiracles on mesothorax.

Abdomen dark yellow except in the light yellow tube. In each abdominal segment yellow pigment appeared to be concentrated in the form of transverse stripes along the center. Neither spiracles nor pori visible.

Setae except the terminal acuminate seta on the tube are of acute type. Chaetotaxy shown in Figure 7.

Stage II Pupa

Pupa reddish-yellow. Body length of male pupae 1.35-1.51 mm ($\bar{x}$±SD = 1.43±0.14 mm, N = 5), female pupae 1.84-2.08 mm ($\bar{x}$±SD = 1.93±0.15 mm, N = 6).

Head light yellow. Antennae translucent and colorless; antenna enclosed in a sheath and attached to the lateral margin of the head, extending ventrally beyond the anterior end of the pronotum (Figure 8). Eyes dark brown and ca. 1/3 as long as the head dorsally. Ocelli absent. Mouth parts not apparent.

Thorax reddish-yellow. Wing buds colorless, extending dorso-laterad along the margin of the thorax and curving back towards the mid-line at the abdominal segment III. Mesothoracic wing buds above the metathoracic pair. Legs pale yellow proximally and colorless distally. One pair of spiracles on mesothorax.

Abdomen reddish-yellow. Neither spiracles nor pori visible.

Setae acute to flagelliform except for the terminal acuminate seta on the tube. Chaetotaxy shown in Figure 8.

Identification of Immature Stages

Few keys are available for the identification of the immature stages of Thysanoptera (H. A. Denmark, personal communication, 1978). At present there is no key to distinguish *G. fuscus* immature stages from those of other phlaeothripids. The key given below enables one to distinguish between stage I and II larvae in particular and also among prepupa, stage I and II pupae.

Key to Larvae, Prepupa and Pupae

1. Antennae segmented and directed forward, always free (Figures 4, 5); mouth parts clearly visible; wing buds absent; abdominal spiracles present 2

1'. Antennae with segmentation unclear, directed laterad, either free or attached to the lateral margin of the head (Figures 6, 7, 8); mouth parts not apparent; wing buds may be present; abdominal spiracles absent 3

2. Third antennal segment bulbous and shorter than the fourth (Figure 9); only 1 transverse row of dorsal crateriform setae on meso- and metathorax; inner pair of dorsal setae on abdominal segment IX shorter than the outer pair (Figure 11); abdominal

segment X with 4 pairs of terminal setae ....Stage I larva

2'. Third abdominal segment claviform and longer than fourth (Figure 10); two transverse rows of dorsal crateriform setae on meso- and metathorax; dorsal setae on abdominal segment IX subequal (Figure 12); abdominal segment X with 5 pairs of terminal setae ....Stage II larva

3. Antennae free, stubby and directed laterad (Figure 6); wing buds absent ....Prepupa

3'. Antennae attached laterally to the head (Figures 7, 8); wing buds present 4

4. Antennae usually not extending beyond the anterior margin of the pronotum (Figure 7); eyes ca. 1/4 as long as the head dorsally; wing buds not extending beyond abdominal segment II ....Stage I pupa

4'. Antennae extending beyond the anterior margin of the pronotum (Figure 8); eyes ca. 1/3 as long as the head dorsally; wing buds reaching third abdominal segment ....Stage II pupa

Summary

There are 6 immature stages of *G. fuscus*. The egg has a chorion with reticulated sculpturing at one end. The other immature stages (stage I and II larvae, prepupa, stage I and II pupae) differ from each other in the structure of their antennae and chaetotaxy.

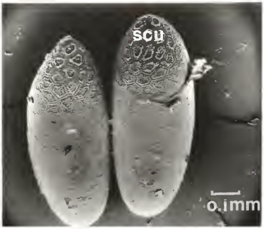

Figure 2. Lateral view of the egg, Gnophothrips fuscus. (SCU, sculpturing of chorion).

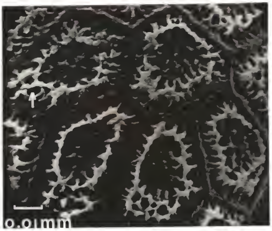

Figure 3. Polygonal areas with openings (see arrow) in reticulate sculpturing of the egg, Gnophothrips fuscus.

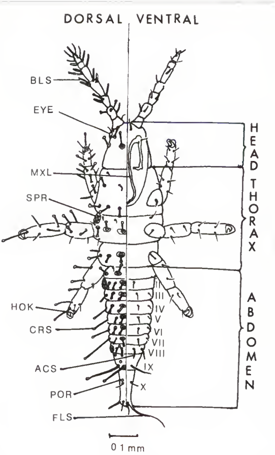

Figure 4. Stage I larva, Gnophothrips fuscus. (ACS, acute seta; BLS, blunt seta; CRS, crateriform seta; FLS, flagelliform seta; HOK, hook; MXL, maxilla; POR, pori; SPR, spiracle).

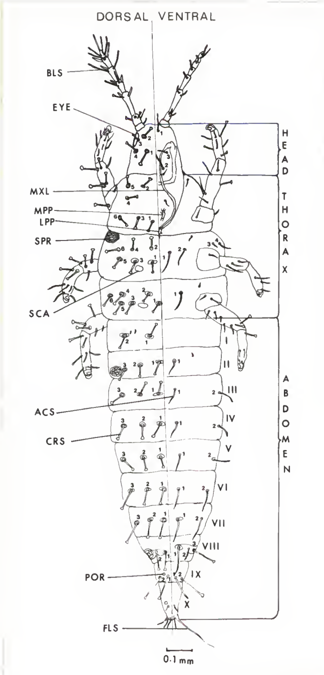

Figure 5. Stage II larva, Gnophothrips fuscus. (ACS, acute seta; BLS, blunt seta; CRS, crateriform seta; FLS, flagelliform seta; LPP, labial palp; MPP, maxillary palp; MXL, maxilla; POR, pori; SCA, sclerotized area; SPR, spiracle)

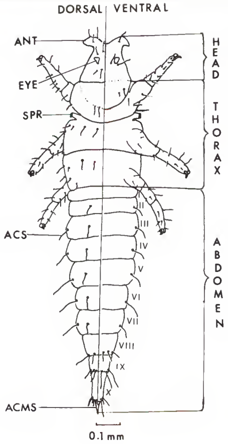

Figure 6. Prepupa, Gnophothrips fuscus. (ACS, acute seta; ACMS, acuminate seta; ANT, antenna; SPR, spiracle).

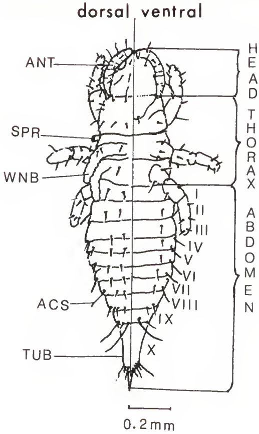

Figure 7. Stage I pupa, Gnophothrips fuscus. (ACS, acute seta; ANT, antenna; SPR, spiracle; TUB, tube; WNB, wing bud).

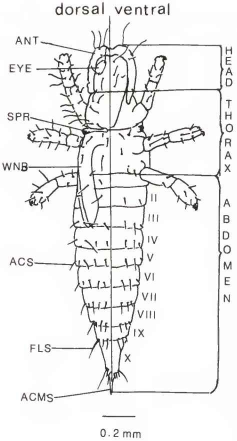

Figure 8. Stage II pupa, Gnophothrips fuscus. (ACS, acute seta; ACMS, acuminate seta; ANT, antenna; FLS, flagelliform seta; SPR, spiracle; TUB, tube; WNB, wing bud).

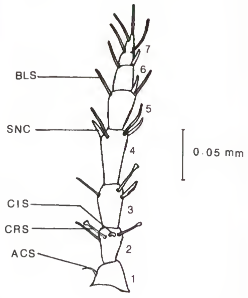

Figure 9. Dorsal view of right antenna of stage I larva, *Gnophothrips fuscus*. (ACS, acute seta;, BLS, blunt seta; CIS, circular sensorium; CRS, crateriform seta; SNC, sense cone).

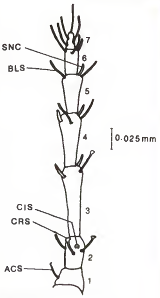

Figure 10. Dorsal view of right antenna of stage II larva, *Gnophothrips fuscus*. (ACS, acute seta; BLS, blunt seta; CIS, circular sensorium; CRS, crateriform seta; SNC, sense cone).

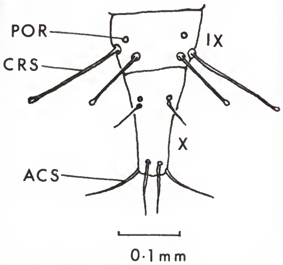

Figure 11. Dorsal view of abdominal segments IX-X of stage I larva, Gnophothrips fuscus. (ACS, acute seta; CRS, crateriform seta; POR, pori).

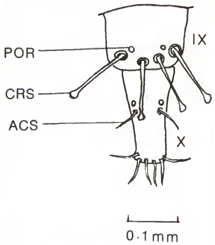

Figure 12. Dorsal view of abdominal segments IX-X of stage II larva, Gnophothrips fuscus. (ACS, acute seta; CRS, crateriform seta; POR, pori).

CHAPTER IV
OCCURRENCE, DEVELOPMENT AND BEHAVIOR OF IMMATURE STAGES

Introduction

Very little is known about the occurrence, development and behavior of *G. fuscus* immature stages. The "nymphs" of this insect were found during July on current growth of vegetative shoots of Austrian pine growing in N. Y. (Crawford 1938). They were also collected during August on vegetative shoots of jack pine, *Pinus banksiana* Lamb., in Ontario, Canada (Lindquist and Harnden 1957).

The times, places of occurrence and developmental changes of *G. fuscus* immature stages on slash pine are reported here. The behavior of larval and pupal stages is also reported.

Materials and Methods

Sampling of Soil

During December 1977, three soil samples were collected from the top layer (5.0-7.5 cm) underneath 3 mature slash pines growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County

FL. These samples were transported to the laboratory in kraft paper bags. Each sample was kept in a Berlese funnel maintained at 42±3°C for 1 week. The emerging insects were collected in a 36-oz Whirl-pak® polyethylene bag containing 70% ethyl alcohol and microscopically examined for G. fuscus immature stages.

Sampling of Bark

During winter (December 21 - March 21) of 1978 and of 1979 a 15 x 10 cm bark sample was chiseled from a branch at the lower, middle and upper crown of 50 slash pines growing in Alachua, Baker, Columbia and Gilchrist Counties in FL. In addition five 3-year-old slash pines grown outdoors in pots at the Forest Insect Research Laboratory of the University of Florida were artificially infested with G. fuscus adults during August 1978 and the bark of these plants was examined during the following winter. In the laboratory the bark samples were broken into small pieces and sieved through a 32-mesh copper screen on to a square-ruled white paper. This paper was then examined under a dissecting microscope to find G. fuscus immature stages. The bark remnants were kept in a Berlese funnel maintained at 42±3°C for 3 days and the emerging insects collected in 70% ethyl alcohol were observed under a dissecting microscope.

Sampling of Shoots

From December 1977 through June 1979, ten 15-cm-long terminal vegetative shoots were sampled monthly from young (less than 6 years old), intermediate (6-15 years old) and mature (over 15 years old) slash pines growing in Alachua and Baker Counties. These shoots were selected from different crown levels. The developing shoots were dissected under a microscope to record the location, number and stage of development of G. fuscus found. The mature shoots were beaten onto a metal garbage can cover painted white to collect G. fuscus present.

The male and female strobili (see page 68 for a definition) were dissected under a microscope to find whether G. fuscus immature stages inhabited these structures.

Laboratory Rearing

All laboratory rearings were done at 22±1°C and 12L: 12D photoperiod. Laboratory-reared and field-collected eggs were used for rearing. A camel hair brush was used to transfer the eggs into pencil-drawn circles on a filter paper kept in a Petri dish. The circles were numbered to identify the eggs within them. Up to 10 eggs were kept per filter paper. Each Petri dish was clamped with 2 heavy-duty binder clips. The filter papers were moistened and the eggs were examined daily until larvae emerged.

Larvae were reared on rapidly-growing vegetative shoots of young slash pines. The shoot cut with a pre-sterilized knife was immersed in distilled water for ca. 15 minutes. The excess water was shaken off and the base of the shoot was waxed (61°C paraffin wax) twice. Each shoot was examined to ensure the absence of other insects and possible natural enemies of thrips. A camel hair brush was used to introduce up to 5 newly-hatched larvae per shoot. Each shoot was kept in a 24-oz Whirl-pak® polyethylene bag containing a moistened filter paper. The developmental changes of these larvae were recorded once every 1-2 days and the shoots were replaced weekly. Prepupae were transferred to Petri dishes with 2 filter papers and heavy-duty binder clips. The developmental changes of pupae were recorded daily until adults emerged.

Results and Discussion

Occurrence of Immature Stages

Immature stages of *G. fuscus* were not found in the soil samples. The bark samples collected from naturally occurring slash pines did not contain *G. fuscus* but adults of *Leptothrips pini* (Watson) (Thysanoptera: Phlaeothripidae)[1], *Karnyothrips* spp (Thysanoptera: Phlaeothripidae) and larvae of an unidentified phlaeothripid were found in these. During winter *G. fuscus* adults were found under the bark of young slash pines artificially infested during the previous summer and grown outdoors in pots near the Forest Insect Research

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[1] Identified by H. A. Denmark of the Division of Plant Industry, Florida Department of Agriculture and Consumer Services, Gainesville, FL

Laboratory. At the same time eggs and stage I larvae were collected from the shoots of these plants. But during winter field-collected shoots of young slash pines did not have any immature stages.

All the developmental stages of G. fuscus were found during spring (March 21 - June 21) and summer (June 21 - September 21) on rapidly growing vegetative shoots of young and intermediate slash pines. The eggs were collected from March through October from current growth of vegetative shoots of young slash pines. The eggs were found on the shoot stem, near the bases of needle fascicle sheaths. The eggs were laid either singly or in clusters of 2-4. The maxima of eggs per shoot was 32. Stage I and II larvae were found between April and September. These larvae were observed on the shoot stem and among the needles. The maxima for larvae observed per shoot were 9 and 12 for stage I and II larvae respectively. Pupae were seen less frequently than the other developmental stages. They were found from May through September. Prepupae as well as stage I and II pupae were found appressed between bases of needle fascicle sheaths and shoot stem. The maxima for prepupae, stage I and II pupae observed per shoot were 2, 4 and 4 respectively.

There were no immature stages of G. fuscus on mature vegetative shoots of slash pines. The shoots of mature slash pines did not have these immature stages. Once the eggs and stage I larvae were collected from stalks of young female strobili in March. Neither catkins nor the second-year cones had immature stages of G. fuscus.

Development of Immature Stages

The durations of the laboratory-reared eggs, larval stages I and II, prepupa and pupal stages I and II of G. fuscus are shown in Table 1. In the laboratory the mean duration of all the immature stages combined was ca. 46 days at 22±1°C. This is long compared to the total durations ranging from 24-39 days reported in literature for the immature stages of other phlaeothripids reared at temperatures varying from 23-29°C (Loan and Holdaway 1955, Lewis 1973, Maddox and Mayfield 1979). Although the durations of G. fuscus larval and pupal stages were comparable to those reported for other phlaeothripids, G. fuscus eggs took an unusually long time to hatch. In the field, ambient temperature being higher than 22°C during spring

Table 1. Duration of the immature stages of Gnophothrips fuscus laboratory-reared at 22±1°C and 12L:12D photoperiod.

Stage of development	N	Duration in days	
		Range	Mean
Egg	26	11-19	14.8
Stage I larva	6	11-16	12.5
Stage II larva	4	9-13	10.3
Prepupa	4	1.7-3	2.0
Stage I pupa	4	3-4	3.3
Stage II pupa	4	3-4	3.5

and summer (see Figure 15, page 56) the duration of G. fuscus immature stages is likely to be shorter than what was observed in the laboratory.

Egg. The color of the egg changes from light to dark amber and the reticulate pattern becomes more apparent with development. Between 48-72 hr before hatching reddish-brown eye spots and pale black antennae of the larva developing inside are visible. A transverse rupture line appears along the reticulate area of the egg immediately before the eclosion of the larva. The larva emerged head first, pushing a portion of the sculptured end of the egg as a cap. The empty egg shell is uniformly light brown. About 90% of the eggs hatch under laboratory conditions.

Larvae. The color of stage I larva changes from pale yellow to yellow and the length increases by ca. 1.5X at maturity. The mortality (dead or missing) rate was ca. 80% for laboratory-reared stage I larvae. In stage II larva, color changes from yellow to orange-yellow and the length increases by ca. 2X with development. About 60% of the laboratory-reared stage II larvae survived.

Pupae. In prepupa and stage I pupa there are no noticeable changes either in color or in size during development. All laboratory-reared prepupae and stage I pupae survived. Stage II pupa changes from yellow to brownish-yellow with development. About 24-36 hr before the emergence of the adult, the extremities of the wing buds, legs and the base of the tube become pale black; roughly triangular pale black areas are apparent dorsally and ventrally on the prothorax; on meso- and metathorax rectangular pale black areas develop ventrally. By this time anterior half of abdominal segments I-IX is black and the posterior half remains yellow. The tube is yellow in the anterior half and black in the posterior half. All laboratory-reared stage II pupae survived.

Behavior of Larvae, Prepupa and Pupae

The larvae walk actively but never jump. They are positively thigmotactic but avoid bright light and heat. Stage I larvae survive for 3 days and stage II larvae for 7 days, on moistened filter paper kept in clamped Petri dishes. These larvae die within 48 hr on dry filter papers. Upon maturity stage II larvae cease to be active and move to a darker place (viz. between the base of the needle fascicle sheath and the stem of the shoot in the field or between the filter papers when reared in the laboratory).

Prepupae and other stages of pupae are quiescent, non-feeding and move sluggishly when touched. They also move away from heat but are more tolerant than larvae to bright light.

Summary

The immature stages of G. fuscus were found during spring and summer on rapidly growing vegetative shoots of young slash pines. Once they were observed during early spring on young female strobili. At 22±1°C the laboratory-reared *G. fuscus* developed from egg to adult in ca. 46 days. The developmental changes and mortality rate of immature stages are reported. The larvae and pupae are positively thigmotactic but moved away from bright light and heat.

CHAPTER V
LIFE HISTORY AND SEASONAL ABUNDANCE OF LIFE STAGES ON SLASH PINE

Introduction

Very little has been reported on the life history of *G. fuscus*. Immature stages of this insect occur on the current vegetative growth of slash pines in pitch-cankered plantations in Florida (R. C. Wilkinson, personal communication, 1978). The "nymphs" and pupae of this thrips were collected during July from growing tips of Austrian pine in New York (Crawford 1938) and "nymphs" alone were observed during August on jack pine shoots in Ontario, Canada (Lindquist and Harnden 1957). In Florida, the adults of this insect have been collected at different times of the year (Ebel 1961, Hood and Williams 1915, Morgan 1913).

The objective of the study reported in this chapter was to investigate the life history and seasonal abundance of *G. fuscus* on slash pines growing in a seed production area located in northeastern Florida.

Materials and Methods

Young Slash pines

The young (2-5 yr old) slash pines used in this study were growing in an understory of a mixed longleaf and slash pine stand at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL. Of these, 100 rapidly growing[1] slash pines (Bennett 1963) were selected because preliminary observations in 1978 indicated the presence of *G. fuscus* immature stages on them.

From April 1979 through May 1980 the current vegetative growth of 15 shoots were collected from 15 slash pines in the study area. These samples were collected at 1-2 week intervals from April through September and monthly otherwise. Each shoot was individually sealed in a plastic bag and transported on ice to the laboratory where it was examined under a dissecting microscope to record the location, number and life stage of *G. fuscus* found.

Mature Slash Pines

During 1979, two shoots per quadrant were beaten onto a beating lid, i.e., a garbage can cover painted white, to collect *G. fuscus* from 6 slash pine seed trees grown at the Ocean Pond Experimental Area "E". This was done monthly throughout the year. In addition during November and December of 1979 a branch from 4 mature slash pines growing at this experimental site was collected to find the presence of G. fuscus on them. A 15-cm-long section from the base, middle and the terminal sections of the branch was selected and transferred individually into a large plastic bag. These samples were stored on ice in a cooler-chest and later examined in the laboratory.

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[1] Young slash pines complete 25% of the height growth by the end of March; 52% by the end of April and 85% by the end of June.

Results

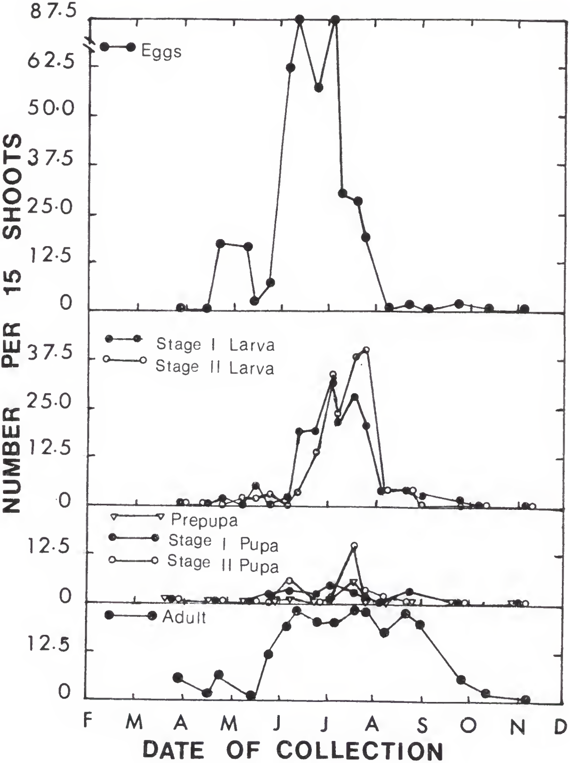
Young Slash Pines

The relative abundance of G. fuscus life stages (Figure 15) and its life history (Figure 16) are based on the observations from April 1979 through May 1980. The adults of G. fuscus were not found on the shoots sampled during winter (December 21 - March 21). The earliest date of collection of adults was in early spring (March 22). The number of adults on shoots sampled remained low until late spring. Their numbers were high through most of summer (June 21 - September 21) and declined in fall (September 21 - December 21).

Gnophothrips fuscus eggs were not found on shoots sampled during winter. These eggs were first collected in mid-spring (April 15). The number of eggs per sample increased sharply during early summer (Figure 15) and

Figure 13. Seasonal abundance of Gnophothrips fuscus life stages on shoots of young slash pines growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL (1979 April - 1980 May)

Note: Observations for April and May are the averages of the numbers for 1979 and 1980. No G. fuscus were collected from these plants from December through February.


87.5
62.5
50.0
37.5
25.0
12.5
0
Eggs
37.5
25.0
12.5
0
Stage I Larva
Stage II Larva
12.5
0
Prepupa
Stage I Pupa
Stage II Pupa
12.5
0
Adult
NUMBER PER 15 SHOOTS
F
M
A
M
J
J
A
S
O
N
D
DATE OF COLLECTION

remained high until mid-summer. Then there was a decline through early fall; none was collected after September 25. There was an average of 25 eggs per sample of 15 shoots.

The stage I larvae were first collected on April 21. The number of stage I larvae remained low during spring but gradually increased in summer to reach a peak in June. Their number declined through fall and none was found after September 25. The average number of stage I larvae per sample was 9.

The stage II larvae were first collected during late spring (May 8); their numbers increased sharply to reach a peak in late summer (July 24) and dropped precipitously towards the end of summer. These larvae were not collected after September 25. An average of 9.5 stage II larvae per sample were collected.

The prepupae and stage I and II pupae were less abundant than the other stages of development. These were collected infrequently. Their average numbers per sample were 0.5, 1.8 and 1.9 respectively.

Mature Slash Pines

The numbers of *G. fuscus* collected by beating shoots from mature slash pines are shown in Table 2. Only adults were collected by this method. The numbers of adults fluctuated widely. A high of 48 adults were collected during April but none was found in the sample taken in December. Only the shoots of the branches sampled in November and December had *G. fuscus* adults on them.

Table 2. The numbers of Gnophothrips fuscus collected by beating 2 vegetative shoots per quadrant from 6 cone-bearing slash pines growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL (1979).

Month	Tree number						Total
	1	2	3	4	5	6	
March	3[b]	4	2	2	0	6	17
April	5	6	12	14	2	9	48
May	2	2	4	4	6	10	28
June	4	3	4	3	2	2	18
July	5	5	2	9	4	13	38
August	0	2	1	5	1	4	13
September	3	3	1	1	1	0	9
October	3	8	2	2	5	4	24
November	1	1	0	4	2	3	11
December[a]	0	0	0	0	0	0	0

Note: Each observation is the total catch from 8 shoots.

a. The shoots were wet after a heavy rain during previous night.

b. Only adults were collected.

Discussion

Young Slash Pines

The adults appeared on young slash pines concurrent with the onset of rapid vegetative growth (Bennett 1963, McGraw 1975) on these plants. Presumably these adults moved from the overstory slash pines where they were feeding on conelets during winter (see page 79). By the time these thrips moved onto young slash pines the conelets in the overstory slash pines have reached stage IV of development (Rockwood 1978) and were no longer being fed upon by thrips (see page 79). Apparently G. fuscus adults were moving to oviposit on young slash pines after feeding on conelets. Dickman and Kozlowski (1969) reported that highest concentration of most macro- and micronutrients occur early in the development of cones in Pinus resinosa. This implies that G. fuscus were moving to oviposit after a nutrient rich diet. The increase in the number of adults in early summer coincided with the emergence of "new" adults from young slash pines in the study area. The decline in their number during fall followed the completion of most of the height growth in young slash pines (Bennett 1963) and the consequent cessation of G. fuscus breeding activity on these plants.

The first collection of eggs was 3 weeks after the appearance of adults on young slash pines. This is unlikely because even newly-emerged thrips adults rarely have a pre-oviposition period of over 2 weeks (Lewis 1973). The decline in the number of eggs, despite the presence of a large number of adults during late summer, may be due to an increase in the number of "older" female adults. Such females are known to lay fewer eggs than the "new" adults (Lewis 1973).

Despite the egg and instar I larva having about the same length of development, the average number of larvae per sample was ca. 40% of that of the eggs. This probably indicates the greater effect of natural mortality factors on stage I larvae than on the eggs. This higher mortality was true for laboratory-reared stage I larvae also (see page 36).

The pupal stages were collected less frequently than the other stages perhaps becuase of their shorter lengths of development (see Table 1 in page 35).

The observed and estimated[1] occurrence of G. fuscus life stages are shown in Figure 14.

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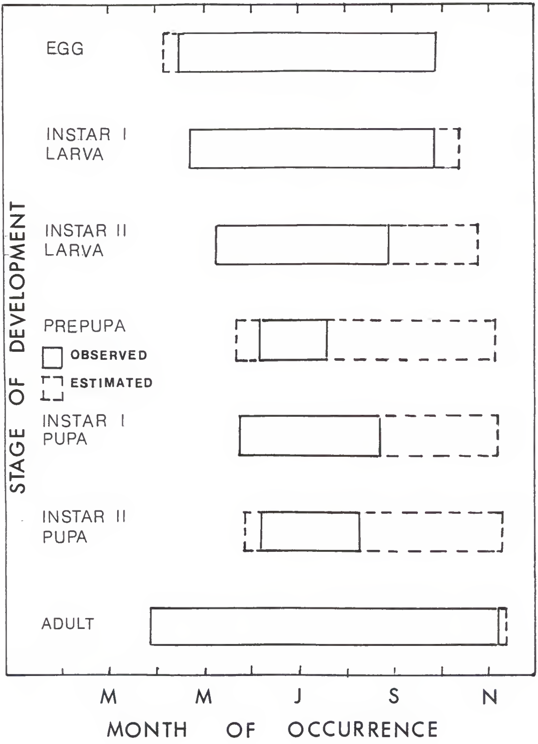
[1] The dates of estimated occurrence of developmental stages were calculated on the basis of the earliest (or latest) date of collection of a given stage and the duration of other immature stages in the laboratory at 22°C (as such these dates are only approximations because ambient temperatures in the field invariably are higher during summer) e.g. earliest date of occurrence was calcualted on the basis of April 21 collection of stage I larvae; the eggs were estimated to be in the field by April 06, i.e., 15 days before stage I larvae because eggs on the average hatched in 15 days. The last date of estimated occurrence was similarly based on September 25 collection of eggs from the field.

Figure 14. Observed and estimated occurrence of Gnophothrips fuscus life stages on shoots of young slash pines growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL (1979-1980).


EGG
INSTAR I LARVA
INSTAR II LARVA
PREPUPA
OBSERVED
ESTIMATED
INSTAR I PUPA
INSTAR II PUPA
ADULT
STAGE OF DEVELOPMENT
M
M
J
S
N
MONTH OF OCCURRENCE

These observations suggest that the life history of G. fuscus is synchronized with the vegetative growth of young slash pines in this study area. The adults moved onto these plants in March and their reproductive activity remained high during summer. The vegetative height growth of young slash pines begins in March (Bennett 1963) and the succulent growth of needles occurs during summer (McGraw 1975). In slash pine relatively higher nitrogen content was found in the current growth than in the other tissues (Smith and Stanley 1967b). It is possible that G. fuscus were attracted to the current vegetative growth because of this higher nitrogen content.

The developmental stages of G. fuscus were found during a period of 160 days (April 15 - September 25) on the shoots of young slash pines. At least 3 generations of this insect should have occurred during this period as estimated on the basis of 46 days taken by laboratory-reared G. fuscus to develop from egg to adult. The ambient temperatures during summer being higher than 22°C fewer than 46 days may be required by this insect to complete its life cycle in the field.

Mature Slash Pines

The fluctuation of the number of G. fuscus collected by beating of vegetative shoots on mature slash pine may be due to the method used. With the beating lid the best results were obtained on sunny and calm days. Thrips were not collected when wet shoots were beaten (see page 45). During gusty winds thrips drifted off the beating lid. This method is useful to detect the presence of _G_. _fuscus_ on slash pines, though.

There was no clear relationship between the number of _G_. _fuscus_ adults collected by beating shoots of mature slash pines and that of those caught on sticky traps hung at mid- to upper crown of these trees (see page 54).

Summary

All the life stages of _Gnophothrips_ _fuscus_ were collected from the current vegetative growth of young slash pines during spring and summer. The relative abundance of these stages on young slash pines growing in a seed production area is shown. Based on the laboratory-rearing data it is estimated that at least 3 generations of this insect occur on young slash pines during spring and summer.

Only adults of _G_. _fuscus_ were collected by beating vegetative shoots of cone-bearing slash pines in a seed production area. The monthly catches of these adults varied widely; none was caught when wet shoots were beaten.

CHAPTER VI

SEASONAL ABUNDANCE OF ADULTS FLYING WITHIN CROWNS OF SLASH PINES IN A SEED PRODUCTION AREA

Introduction

In the literature little is reported on the seasonal abundance of *G. fuscus* adults. They were observed on slash pine vegetative shoots during early January, on female strobili buds during February and on conelets and vegetative shoots until mid-May (Ebel 1961). Once *G. fuscus* adults were found on male strobili (DeBarr 1969) in mid-January. Within the crowns of 12 mature slash pine seed trees in northeastern Florida there were no significant differences either in the mean number of female strobili attacked by thrips among directional quadrants or in the mean percentages of thrips-killed conelets between the lower and upper levels (DeBarr *et al*. 1975). The objective of the study reported in this chapter was to determine the seasonal abundance of *G. fuscus* adults flying within the crowns of similar seed trees at the same location.

Materials and Methods

This study was conducted from December 1977 through November 1979 at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL. Six slash pine seed trees growing in a well-drained area with longleaf and slash pines were chosen on the basis that they were open grown with well-developed crowns (similar to trees in seed orchards). These trees ranged from 17-20 years in age and ca. 13-18 m in height. Each tree was demarcated into east, north, south and west quadrants at mid-crown, by tying yellow plastic flaggings onto branches along NE, SE, NW and SW compass bearings.

Yellow plastic discs (15 cm in diam) and sprayed on one side with Tanglefoot® insect adhesive were used to trap thrips. One trap per quadrant was hung on a shoot at the upper half of the crown of each tree selected, by using a nylon cord which allowed the trap to rotate freely. These traps were replaced monthly. In the laboratory xylene was used to remove thrips from the traps. The mean number of thrips per trap was calculated for each sample of 24 traps and a graph was plotted with the date of collection along the abscissa and the mean number of thrips / trap / month along the ordinate.

The probability of a given trap having a catch, in a given quadrant and for a given season, was calculated to find any significant differences among seasons, in the mean numbers of G. fuscus trapped. The procedure used was to:

1. Count the number of traps with and without a catch / quadrant / season,
2. transform the "zero" counts to X+0.5 and "eighteen" counts to X-0.5,
3. fit the transformed data into the reduced logit model:

$$\mathrm{Ln}\left(\frac{N_n}{N_y}\right) = \mu + Y_i + S_j + S(Y)_{(i)j} \text{ (also see Appendix D).}$$

The FUNCAT program of the Statistical Analysis System (SAS Institute Inc., N. C.) was used to analyze the data to find whether there were significant differences, among the quadrants and seasons, in the probability of a given trap having a catch.

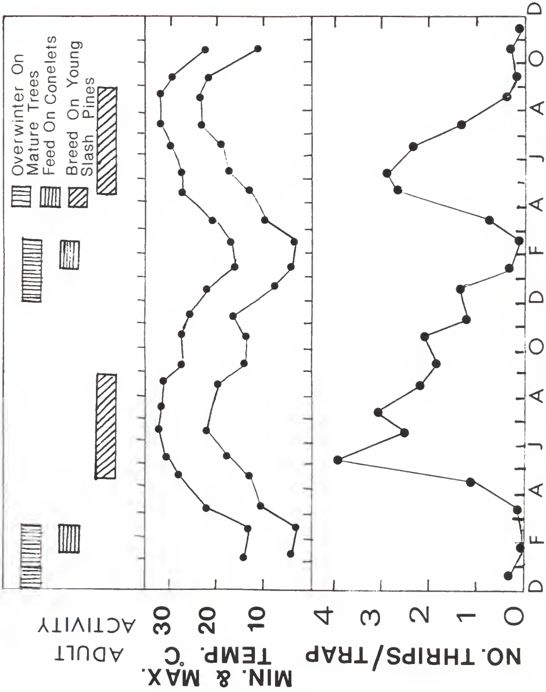
Results and Discussion

The mean numbers of thrips trapped monthly are shown in Figure 15. All the G. fuscus adults caught in these traps were macropterous indicating that they were the principal dispersing form of this insect.

The mean number of thrips caught was lowest during winter (December 21 - March 21). Low ambient temperatures (Figure 15) and short days during this season may have resulted in low catches because temperature and light are considered the most important of the factors affecting

Figure 15. Activities of *Gnophothrips fuscus* adults (top), mean monthly averages of maximum and minimum temperatures (middle) and mean monthly catches of *Gnophothrips fuscus* adults / trap (bottom) in 24 sticky traps hung in the crowns of 6 slash pine seed trees growing at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL (December 1977 - November 1979).

Note: The temperature data are from U. S. National Weather Service Station No. 08 located at the Division of Forestry in Lake City, FL


ADULT ACTIVITY
Overwinter On Mature Trees
Feed On Conelets
Breed On Young Slash Pines
MIN. & MAX. TEMP. °C
30
20
10
NO. THRIPS/TRAP
4
3
2
1
0
D
F
A
J
A
O
D
F
A
J
A
O
D
MONTH OF OBSERVATION

take-off and flight of thrips (Lewis 1973). The period of low flying activity also coincided with G. fuscus adults feeding on female strobili during late winter. This suggests that thrips which feed on female strobili of a given slash pine probably overwintered on the same tree.

The number of thrips trapped increased early during spring (March 21 - June 21) to reach a peak in May (Figure 15). Increasingly higher ambient temperatures and longer days were apparently more favorable for thrips flights during this season. During late March G. fuscus adults began to appear on vegetative shoots of young slash pines in and around the study area (see page 41) suggesting that they fly from mature trees to young slash pines to reproduce.

The number of thrips trapped declined during summer (June 21 - September 21) despite high temperatures and long days. This suggests that few of the "new" adults emerging from the young slash pines in and around the study area moved back to the larger trees in the immediate vicinity.

The sticky trap catches continued to decline during fall (September 21 - December 21). During this season the reproductive activity of G. fuscus on young slash pines in the understory ceased (see page 44). Thus there were no signs of "mass-flights" of G. fuscus adults back to the mature slash pines in the overstory.

The analysis of the data[1] fitted into the reduced logit model showed that among seasons, the probability of a given trap having a catch in a given quadrant was significantly different (X^2 = 79.42*** with 3 df). But the year x season interaction was also significant (X^2 = 57.15*** with 3 df) indicating that seasonal trends may vary from year to year. These yearly variations in seasonal abundance of *G. fuscus* may be due to the annual variations in the female strobili crop which is dependent upon environmental factors and the history of insect infestations (Varnell 1976). There was no significant difference (X^2 = 0.95 NS with 3 df) among quadrants of these trees, in the probability of a given trap in a given season having a catch. These results agree with those of DeBarr *et al*. (1975) who reported lack of significant differences among quadrants on 12 slash pines, in the number of female strobili attacked by thrips.

Summary

The number of *G. fuscus* adults caught on 24 sticky traps hung within the crowns of 6 slash pine seed trees, was lowest during winter, increased to reach a peak during spring and then gradually declined through summer and fall. Apparently the adults feeding upon the conelets overwintered on the same slash pine. There were significant differences among seasons and in year x season interaction in the probability of a given trap having a catch. This probability was not significantly different among directional quadrants of slash pine seed trees.

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[1] Done by Richard Lynch of the IFAS Statistical Unit, University of Florida, Gainesville, FL

CHAPTER VII
VERTICAL DISTRIBUTION OF ADULTS FLYING IN A SLASH PINE SEED ORCHARD

Introduction

Many species of thrips are known to disperse from their breeding sites (Lewis 1973). During spring through summer *G. fuscus* breed on the current growth of vegetative shoots on young slash pines (see page 43). The adults of this insect feed upon the young slash pine conelets during winter (Ebel 1961). The vertical distribution of *G. fuscus* in flight has not been investigated. The results of a study to determine the pattern of vertical distribution of *G. fuscus* flying among slash pines in a cone-producing seed orchard located in northeastern Florida are reported in this chapter.

Materials and Methods

This experiment was carried out from May 1979 through April 1980 at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL.

The 18-year-old slash pines in this seed orchard were 15-18 m tall and were planted in a 9.14 x 9.14 m (30 x 30 ft) grid pattern. There were young slash pines in the adjoining areas but none occurred in the understory of the trees within this ca. 2 ha orchard.

Sticky traps (see page 53 for details) were used to catch G. fuscus flying at different heights. The arrangement of these traps is shown in Figure 16. Using a truck-mounted hydraulic bucket lift, a nylon cord (3/8 inch and 456 lbs tensile strength) was tied between 2 adjacent slash pines which were at least 15 m tall. Sticky traps were hung at 3, 6, 9 and 12 m intervals[1] above ground on a second nylon cord (line 2) passed through a S-hook attached to the center of the first cord (line 1). Wooden counter-weights (CW) hung at one end of the lines prevented sagging and snapping of lines when the trees swayed. The free end of line 2 was tied, leaving enough length to change the traps from ground, to one of the trees. The experiment had 8 replicates.

The traps were replaced monthly and the number of thrips caught on each trap was recorded. Because the treatment used was quantitative and the increments between successive treatment levels were equal, the coefficient of orthogonial polynomials procedure (Steel and Torrie 1960) was used to analyze the data.

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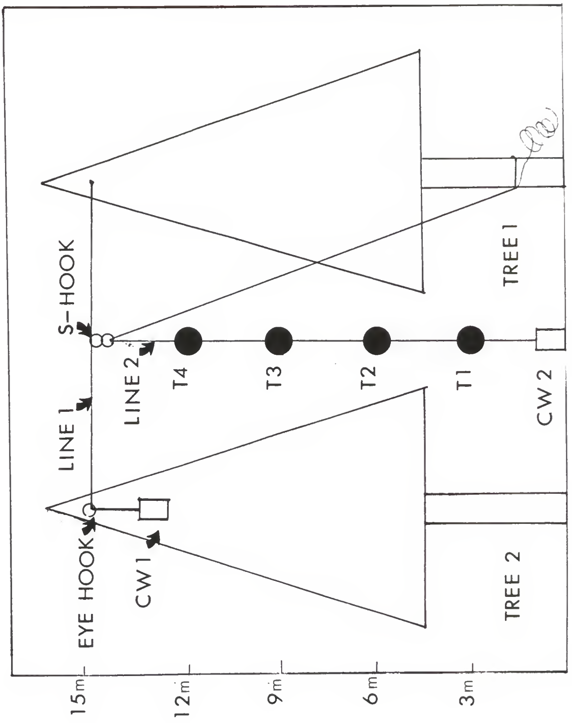
[1] Heights were selected so that traps were at levels corresponding to the bole, lower, middle and upper crown.

Figure 16. Arrangement of sticky traps used to study the vertical distribution of *Gnophothrips fuscus* flying among slash pines at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, Fl. (CW, counter weight; T, sticky trap).


15m
12m
9m
6m
3m
EYE HOOK
CW 1
TREE 2
LINE 1
LINE 2
S-HOOK
T4
T3
T2
T1
CW 2
TREE 1

Results and Discussion

The relationship between the height level of traps above ground and the mean number of thrips caught per trap is shown in Figure 17. Comparatively more thrips were caught on traps hung at levels corresponding to mid- (9 m) and upper (12 m) crown than those at the bole (3 m) and lower crown (6 m) levels. In slash pine most of the conelets occur in the upper half of the crown (Smith and Stanley 1967a, DeBarr *et al*. 1975). Thus more thrips were caught at height levels corresponding to where majority of the conelets are borne. This observation agrees with the finding of DeBarr *et al*. (1975) who reported that the percentages of slash pine conelets killed by thrips did not differ significantly between crown levels.

The ANOVA of the transformed ($\sqrt{X+0.5}$) data using orthogonal polynomials showed a significant linear effect (F = 30.88*** with 1 and 20 df) for the number of thrips caught at different height levels. The quadratic and cubic effects were not significant (F = 2.57 and 0.30 respectively with 1 and 20 df).

The monthly catches of *G. fuscus* adults recorded during this study are shown in Table 3. During November-February *G. fuscus* were not caught on these traps. Similar results were observed in the study on the seasonal abundance of this insect (see page 56). Generally the monthly catches were higher on the traps hung at levels corresponding to the mid- and upper crown. Only during May-June more *G. fuscus* were

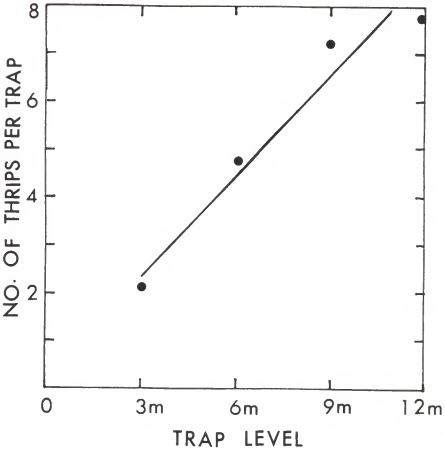


Figure 17. Relationship between the number of Gnophothrips fuscus adults caught per trap and the height level of the trap above ground at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL (May 1979 - April 1980).

Table 3. Number of *Gnophothrips fuscus* adults caught on sticky traps hung at 4 different heights among slash pines growing at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL (May 1979 - April 1980).

Month of collection	Level of the trap above ground				
	3 m	6 m	9 m	12 m	Total
May	3	2	3	10	18
June	4	12	9	3	28
July	5	12	23	22	62
August	3	3	8	12	26
September	2	7	7	6	22
October	0	0	2	0	2
November	0	0	0	0	0
December	0	0	0	0	0
January	0	0	0	0	0
February	0	0	0	0	0
March	0	1	1	4	6
April	0	1	5	5	11

Note: Each observation is the total catch on 8 sticky traps.

caught on the traps hung at lower crown level. This reverse trend in the number of G. fuscus adults trapped corresponded with an increase in the number of adults emerging from young slash pines growing in the areas adjoining to this seed orchard. But this trend did not continue despite persistent emergence of G. fuscus adults through early summer.

Summary

Sticky traps hung at 4 different height levels were used to monitor the vertical distribution of G. fuscus adults flying among cone-producing slash pines in a seed orchard. More thrips were trapped at the height levels corresponding to the mid- and upper crowns of these slash pines. Analysis of the data using orthogonal polynomials showed a significant linear effect in the number of thrips at increasing levels of height; the quadratic and cubic effects were not significant.

CHAPTER VIII
DAMAGE TO SLASH PINE

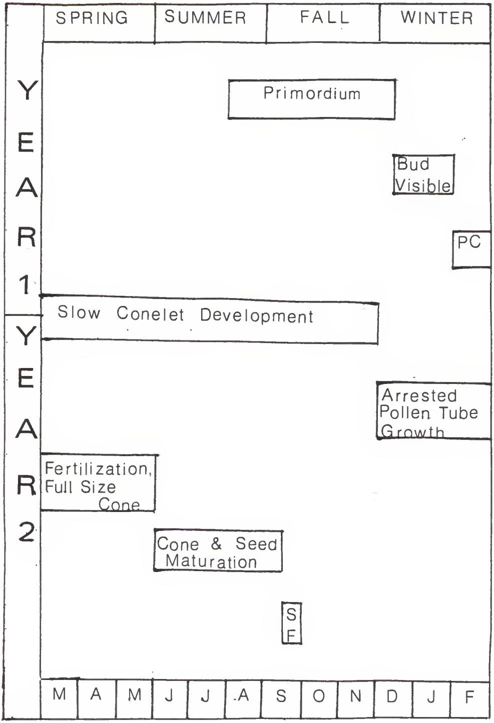
Introduction

Gnophothrips fuscus has been associated with damage to vegetative shoots of pines. Severely stunted needles were observed on nursery stock of Austrian pine infested with this insect (Crawford 1938). On jack pines inhabited by this thrips the needles were unusually short with yellow spots on them (Lindquist and Harnden 1957). No needle damage was apparent due to these thrips on slash pine (Ebel 1961), however.

Slash pine is monoecious and its reproductive structures are referred to as strobili. The strobili are borne in clusters on reproductive shoots (as opposed to vegetative shoots bearing needles). The pollen is produced in male strobili (catkins) and the ovules are found in female strobili. The complete cycle of female strobili development spans over 2 years covering parts of 3 growing seasons (Figure 18). The strobili initiate as primodia during the summer; these become strobili buds once they are externally visible during the following winter. The stages of development of female strobili, from bud stage until pollination

Figure 18. Chronology of slash pine female strobili development in Florida. (PC, period between conelet opening and pollination during which thrips feed upon the conelets; SF, seeds fall).

Note: Based on the details of slash pine female strobili development by Dorman (1976) and Rockwood (1978).


SPRING
SUMMER
FALL
WINTER
YEAR 1
YEAR 2
Primordium
Bud Visible
PC
Slow Conelet Development
Arrested Pollen Tube Growth
Fertilization, Full Size Cone
Cone & Seed Maturation
S F
M
A
M
J
J
A
S
O
N
D
J
F

have been described by Bramlett and Gwynn (1980) and Rockwood (1978) (also see Appendix A). The female strobilus is composed of many sporophylls (scales) attached to a central axis. The lobe near the base of the scale is called a bract. Once emerged from the bud during early winter, the female strobilus is known as a conelet through the first year of development. The conelet consists of pink, succulent and open sporophylls at the time of pollination during late winter. It becomes green and hard with closed sporophylls ca. a week after pollination. The female strobilus is referred to as a cone during the second year of development.

Gnophothrips fuscus adults are known to attack female strobili in slash pine only. These thrips feed upon conelets from bud-break until pollination (Ebel 1961, DeBarr 1969). Although DeBarr (1969) observed large numbers of *G. fuscus* on slash pine male strobili he reported no damage to these catkins. Thrips attacks have not yet being related to the different developmental stages of conelets.

Tiny beads of resin observed on conelets inhabited by thrips have been ascribed to thrips feeding (Ebel 1961, DeBarr 1969). Hitherto no one has induced thrips attacks on slash pine conelets to positively associate this damage symptom with thrips.

Thrips damage to slash pine conelets varies from negligible to ca. 20% conelet mortality (Ebel 1961). Sublethal damage by thrips deform slash pine conelets; damage to even 2-3 immature scales causes poor opening of resulting cones (DeBarr and Williams 1971). The relationship between the degree of thrips damage and mortality of slash pine conelets is not known. Thrips damage to sporophyll tissues has not been studied.

The objectives of this study were to:

1. Describe *G. fuscus* damage to slash pine vegetative foliage.
2. Relate thrips attacks with chronology of conelet development.
3. Determine the symptoms associated with thrips damage, by inducing *G. fuscus* attacks on female strobili.
4. Relate the degree of thrips damage with mortality of conelets.
5. Study thrips damage to sporophyll tissues.

Materials and Methods

Damage to Foliage

Field observations. These observations were carried out during 1979 and 1980 at the USDA Forest Service Ocean Pond Experimental Area "E" located near Olustee in Baker County, FL. At this site 100 slash pines were selected on the basis of their having had a *G. fuscus* infestation during the previous year. These 2-5 yr old pines were ranging from 1-3 m in height and growing in a mixed slash and longleaf pine, *Pinus palustris* Mill., stand. The current vegetative growth of these pines was observed ca. biweekly in 1979 and weekly in 1980 for symptoms associated with thrips damage.

Laboratory observations. During August 1979, four slash pine seedlings grown in clay pots were selected for having damage-free needles and rapid vegetative growth. The mouth of the pot was covered to prevent soil displacement and the plant was immersed for ca. 3 minutes in 1:20 commercial Clorox®:distilled water solution. The plant was then thoroughly washed with a jet of water for ca. 5 minutes and checked to ensure absence of thrips and other natural enemies of thrips. Five field-collected, active adults of G. fuscus were placed on 2 of these plants and 2 others were kept as untreated controls. Each plant was then enclosed in an inverted clear plastic bag supported by a wire frame. The open end of the plastic bag was tightly secured around the rim of the pot to prevent thrips from escaping. These plants were kept under fluorescent light 24 hr per day, watered as necessary, and observed every 2-3 days for 6 weeks.

Relation of G. fuscus Attacks to Chronology of Conelet Development

Thrips damage to female strobili was observed in relation to the chronology of conelet development, from late December through April of 1978/79 and 1979/80 at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL. The observations in 1978/79 were based upon 500 clusters of female strobili (25 from each of 20 ramets[1] belonging to 5 clones); in 1979/80, four-hundred clusters of female strobili (25 from each of 16 ramets belonging to 4 clones) were used. These clusters were tagged when the strobili became visible during winter and the initial condition, number and location of strobili were recorded. These strobili were observed biweekly from December through April i.e. from the first appearance of the buds until the strobili are no longer being fed upon by thrips.

Induction of *G. fuscus* Damage in Female Strobili

During the winter of 1980 four ramets were selected from a slash pine clone (No. 74/61) grown at the University of Florida Clonal Pine Bank located ca. 10 km northwest of Gainesville in Alachua County, FL. During late January 24 clusters of female strobili in stage I (Rockwood 1978) of development were tagged from each ramet. The location, number and condition of strobili in these clusters were recorded. Each cluster was then enclosed in a sleeve cage (modified from Bramlett *et al*. 1977b). This cage consisted of a 46-cm-tall aluminum screen cylinder stapled to one end of a 75.0 x 2.5 x 0.6 cm wooden strip to form a 15-cm-diam cylinder. Each end of the cylinder was covered with masking tape to prevent the metal from tearing the sleeve. The wooden strip was tied onto the shoot at 3 points with pieces of plastic-coated wire. A lump of a sealing compound (Duxseal®) was applied around the shoot and the wooden strip at a point near the basal third of the shoot. The cylinder was enclosed in a closely-fitting nylon organdy (64-mesh) sleeve. The bottom of the sleeve was wound around the Duxseal lump and tied with a plastic-coated wire to prevent movement of insects into and out of the cage. The enclosed shoot was sprayed with Raid® Insect Killer Formula II[2] to kill insects and natural enemies of thrips. The top of the sleeve was tied with another wire.

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[1] Ramet is an independent member of a clone.

Thrips used in this experiment were collected 1-2 days before by beating slash pine vegetative shoots onto a garbage can cover. Up to 5 _G. fuscus_ adults were collected by using a camel hair brush and stored in glass vials containing moistened filter paper and cotton plugs. Two weeks after spraying 2 active _G. fuscus_ adults were introduced onto strobili in half the number of cages. The other strobili were used as controls. These strobili were in stage I of development. The strobili were hand-pollinated and observed for symptoms of thrips damage biweekly from late January through April.

These materials were also used in another experiment to determine whether _G. fuscus_ feeding wounds can be infection courts for pitch canker fungus (see page 86).

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[2] A pyrethrin-based non-residual insecticide.

Relation Between G. fuscus Damage and Conelet Mortality

During the winter and spring of 1980, 50 dead slash pine conelets with thrips damage symptoms were collected from 40 slash pine seed trees growing at McColskey Still Seed Orchard. These conelets were re-hydrated overnight with 0.1% potassium hydroxide solution. The conelets were dissected to determine the number of sporophylls attacked by thrips.

Damage by G. fuscus to Sporophyll Tissues

During the winter of 1979, 10 thrips-damaged conelets were collected from slash pines growing at Ocean Pond Experimental Area "E". A thrips-attacked and an apparently undamaged sporophyll were removed from each of these conelets. These sporophylls were immediately fixed in FAA solution (18 parts 50% ethyl alcohol: 1 part commercial formalin: 1 part glacial acetic acid). A few days later the sporophylls were prepared for sectioning (see Appendix B). Two damaged and 2 undamaged sporophylls embedded in wax were selected and sectioned (20 micron thick) using a rotary microtome (model AO 820). These sections were stained with safranin-fast green series (see Appendix C), mounted in Canada balsam and allowed to dry at room temperature. The stained sections were then observed under a compound microscope to locate thrips damage to the tissues and to compare sections from damaged and undamaged sporophylls.

Results and Discussion

Damage to Foliage

In the field unusually stunted needle growth was not observed on young slash pines infested by *G. fuscus* although distorted needles were found occasionally on these plants. Throughout the spring and summer pale yellowish-white patches were observed on the growing needles of young slash pines inhabited by *G. fuscus* immature stages. About 50% of the needles observed had these patches; these were ca. 1.5-2.0 mm long and were found all around the needle. These patches turned brownish-yellow later in the growing season. The fully grown needles from the previous growing season had yellow to brownish-yellow patches on them. Up to 5 of these patches per needle were found in ca. 80% of the plants observed. The yellow coloration may be due to mesophyll cells changing color as they often do after thrips damage (Lewis 1973). Yellow spots were found on jack pine needles infested by this thrips (Lindquist and Harnden 1957). On new needles of Scotch pine, *Pinus sylvestris* L., *Gnophothrips* spp. damage appeared as small brown patches up to 6 mm long (Wilson 1977). Yellow spots were also observed on Chihuahua pine, *Pinus leiophylla* Schiede and Deppe, needles infested by greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché) (Tooke 1935).

Crescent-shaped, brownish-yellow patches were found on the needles in ca. 50% of the slash pines examined. These patches were usually confined to the lateral edge of the needle. These probably are symptoms of pine needle lesion midge damage (R. C. Wilkinson, personal communication, 1980).

In the laboratory, ca. 4 weeks after the potted plants were exposed to *G. fuscus*, 1-2 mm long yellow spots were observed on 5 growing needles on a plant exposed to thrips. No such yellow spots appeared on the controls. The terminal shoot of one of the controls died due to unknown reasons. At the end of the experiment thrips could not be recovered from the plants.

The above observations suggest that pale yellowish-white patches observed on the growing needles of young slash pines infested with *G. fuscus* are symptoms of thrips damage. This thrips damage to foliage did not seem to have a major impact on the vegetative growth of these slash pines.

Relation of *G. fuscus* Attacks to Chronology of Conelet Development

Thrips damage was not observed on slash pine female strobili buds in stage I of development. DeBarr (1969) noted thrips damage on newly-formed strobili buds during a heavy thrips infestation, however. During early winter dried, opaque resin beads were found on ca. 30% of the terminal vegetative buds and adjoining female strobili buds in stage I of development. Eggs similar to those of pine spittle bug, *Aphrophora* spp. (Homoptera: Cercopidae) were found under the scales of these buds. These eggs were

1.8-2.0 mm long, ca. 0.5 mm wide and flat with one end sharply pointed and darker than the other. These were pale yellow to dark brown. The resinosis was apparently caused by this oviposition. The strobili buds in late stage I of development were occasionally attacked by thrips. *Gnophothrips fuscus* damage was mostly confined to conelets in early stage II through late stage III of development. Thrips attacks ceased once conelets reached stage IV of development as described by Rockwood (1978).

Induction of *G. fuscus* Damage on Female Strobili

Of the 48 strobili clusters exposed to thrips, 30 had 39 strobili with clear droplets of resin on their sporophylls. These symptoms are similar to those described by Ebel (1961). There were no resin beads on the strobili in controls. The damage was confined to the basal third of these conelets. On a few occasions *G. fuscus* adults were observed under the scale leaves of the conelet stalks. Under a dissecting microscope thrips damage appeared as surface scraping of the sporophyll.

Relation Between *G. fuscus* Damage and Conelet Mortality

The dead slash pine conelets with thrips damage had an average of ca. 150 sporophylls. About 7% of these sporophylls (range 3-43) were attacked by *G. fuscus*. Thrips damage to individual sporophylls varied from slight injury to ca. 2/3 of the sporophylll being devoured. In some only the bract was attacked. It was impossible to ascertain whether the conelets were killed by thrips damage alone. In some the axis was necrotic and soaked with pitch suggesting possible frost damage (Hutchinson and Bramlett 1964). Seedbug damage can abort pine conelets (DeBarr and Ebel 1974, Goyer and Williams 1980). Pitch canker fungus infections also kill slash pine conelets at the time of pollination (Miller and Bramlett 1978).

Damage by G. fuscus to Sporophyll Tissues

Few mesophyll cells of thrips-damaged sporophylls were destroyed while this tissue remained intact in undamaged controls (Figure 18 a, b). This feeding damage caused cavity formation in the tissue. Thrips damage to leaf tissues of cotton resulted in similar tissue degeneration (Wardle and Simpson 1927). The degeneration of mesophyll could be due to the action of the digestive enzymes of these thrips. DeBarr and Kormanik (1975) attributed the missing portion of a seedbug-damaged ovule in a conelet to the digestive action of this insect.

Summary

Gnophothrips fuscus damage to foliage of young slash pines apparently caused yellowish-white patches on the growing needles. These patches turned yellow in the fully grown needles. Thrips damage to foliage does not appear to affect shoot growth seriously enough to warrant control measures to prevent it.

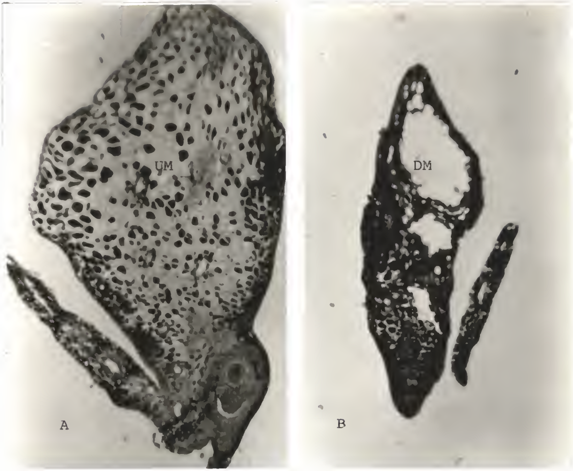

Figure 19. Longitudinal section of a slash pine female sporophyll. a. Undamaged b. Thrips-damaged. (UM, undamaged mesophyll, DM, damaged mesophyll).

Thrips damage was usually confined to slash pine conelets between early stage II and late stage III of growth. Control measures to prevent thrips damage to conelets are deemed necessary during this period which is usually ca. 4 weeks.

Induced damage symptoms of G. fuscus on slash pine conelets were similar to those reported in literature. During early winter, resinosis caused by the probable oviposition of a spittlebug may superficially appear like G. fuscus damage on conelets.

An average 7% of the sporophylls were thrips-attacked in conelets died with symptoms of thrips damage. The degree of thrips injury to individual sporophylls varied, suggesting that other environmental factors may have contributed to the death of these conelets.

Gnophothrips fuscus damage caused histological degeneration of mesophyll tissue in the sporophylls.

CHAPTER IX
ASSOCIATION WITH PITCH CANKER FUNGUS

Introduction

Thrips are known to transmit fungal pathogens by mechanical contact (Sakimura 1947). The only reported association between G. fuscus and a fungal pathogen of a pine species is the collection of this insect from the cankers of comandra blister rust, Cronartium comandrae Pk., in lodgepole pine, Pinus contorta Dougl., in Alberta, Canada (Powell 1971). This thrips has been consistently collected from pitch-cankered slash pine plantations in Florida (R. C. Wilkinson, personal communication, 1978). Hitherto, the incidence of pitch canker fungus, Fusarium moniliforme Sheld. var. subglutinans Wollenw. and Reink., (FMS) on G. fuscus collected from slash pines in pitch-cankered plantations has not been studied.

Pathogenic fungi found either on the epidermis of plants or on the bodies of thrips can infect plant tissues through the feeding punctures of them (Howard 1923). Pitch canker fungus is pathogenic to slash pine conelets at the stage of maximum pollen receptivity (Miller and Bramlett 1978). Such conelets are known to be fed upon by G. fuscus adults (Ebel 1961). It is not known whether the feeding wounds of G. fuscus on slash pine conelets can be infection courts for FMS. Insects are thought to be involved in the pitch canker disease cycle because of: (1) Feeding wounds of some insects, deodar weevil, Pissodes nemorensis (Germar), (Coleoptera: Curculionidae) and subtropical pine tip moth, Rhyacionia subtropica Miller, (Lepidoptera: Olethreutidae) are known to be infected by air-borne FMS spores (Blakeslee et al. 1978, McGraw 1975, Schmidt et al. 1976), and (2) the association of cankers with mechanical and feeding injury (Berry and Hepting 1959, Dwinell and Phelps 1977).

The objectives of the study reported here were to:

(1) Find the incidence of pitch canker fungus on G. fuscus adults collected from pitch-cankered slash pines in a plantation.

(2) Study the possibility of G. fuscus feeding wounds on slash pine conelets being infection courts for FMS.

Materials and Methods

Incidence of FMS on G. fuscus Adults Collected from Slash Pines in a Pitch-cankered Plantation

This was studied from November through December of 1979 at "Norfleet Slash Pine Plantation" located in Gilchrist County, FL. This plantation was selected due to the presence of pitch canker in ca. 50% of the trees; *G. fuscus* adults were found in ca. 60% of the slash pines at the experimental site. These slash pines were planted in 1966 at ca. 2 x 3 m spacings and ranged from 7-10 m in height at the time of this study.

A 30-cm terminal section of a dominant shoot exposed to the sun in the upper crown was used as the sampling unit because *G. fuscus* adults were frequently collected from such shoots. Two samples were taken from 20 slash pines with and 20 without external pitch canker symptoms[1] (Blakeslee *et al*. 1981), taking precautions to avoid their contact with other foliage. One shoot from each tree was beaten 20 times with a clean metal rod onto a cheese-cloth sprayed with Amphyl® disinfectant; 10 pre-sterilized paper points[2] (controls) were spread on this cloth prior to the beating of the shoot. A pre-sterilized camel hair brush was used to collect and transfer each *G. fuscus* adult into a clean, labelled gelatin capsule; a corresponding paper point was selected from the cloth and stored similarly. The other shoot was stored in a kraft paper bag with 10 pre-sterilized paper points. This shoot was dissected under a microscope in the laboratory to collect the thrips and paper points in a similar manner as above. Up to 5 thrips per shoot were collected.

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[1] Copious exudation of pitch through the bark near the canker followed by yellowing of foliage and die-back of branches.

[2] About 5-mm-long roughly triangular pieces of paper usually used in mounting small to minute insects.

These thrips were plated under aseptic conditions in a selective medium (see Appendix E) for FMS. There were up to 4 thrips per plate. The paper points were plated similarly. All the plates were incubated in a culture room under 12 hr of fluorescent light per day at 23±2°C for 2 weeks. All the fungi looking similar to *Fusarium* spp[3] were transferred into culture plates containing 2% water agar and a washed, autoclaved carnation leaf; these plates were incubated and the presence of FMS was determined microscopically[4]. The data were analyzed using a chi square test.

Gnophothrips fuscus Feeding Wounds on Slash Pine Conelets as Infection Courts for FMS

The experimental materials used to induce thrips damage on slash pine conelets (see page 74) were also used in this experiment. Six conelet clusters from each ramet were:

(1) Sprayed with sterile distilled water (control)

(2) Exposed to *G. fuscus* adults and sprayed with sterile distilled water.

(3) Sprayed with a known inoculum of FMS.

(4) Exposed to *G. fuscus* adults and sprayed with the same inoculum as in treatment 3.

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[3] Determined by C. S. Moses, formerly with the Forest Insect Research Laboratory, University of Florida, Gainesville, FL

[4] Determined by S. W. Oak, formerly with the Forest Pathology Laboratory, University of Florida, Gainesville, FL

Thrips were collected 1-2 days before being used, by beating slash pine shoots onto a beating lid. These insects were hand-picked with a clean camel hair brush and up to 4 were stored in clean glass vials containing moistened cotton. Two active G. fuscus adults were introduced onto each strobilus receiving either the treatment 2 (G. fuscus only) or 4 (G. fuscus and FMS inoculum) ca. 2 weeks after the shoots were sprayed with a pyrethrin-based non-residual insecticide (Raid® Insect Killer Formula II). The FMS suspension was prepared by flooding culture plates containing 7-day old AH-1 and AH-2 virulent strains[5] with sterile distilled water. This suspension was adjusted to a concentration of 3.3 x 10^6 spores[6] (both macro- and microconidia) per ml. After thrips damage symptoms were observed on some conelets 2 squirts of the spore suspension were sprayed onto each strobilus receiving treatment 3 (FMS inoculum only) and 4 (G. fuscus and FMS inoculum) by using an atomizer calibrated to deliver 0.66 x 10^6 spores per squirt. The other strobili were sprayed with an equal amount of sterile distilled water. The spores in the inoculum were sprayed onto culture plates containing water agar and found viable before and after spraying. The conelets were pollinated to allow normal development as described by Dorman (1976). These strobili were observed once every 10-14 days during next 8 weeks to collect aborted and dead conelets. Each conelet collected was transferred into a pre-sterilized polyethylene Whirl-pak® bag, sealed, labelled and stored in a cooler chest. In the laboratory, under aseptic conditions, each conelet was dipped in 95% ethyl alcohol for ca. 5 sec and flamed. A chip of the inner core of the conelet was removed with a sterilized scalpel and plated in the Fusarium medium as described by Nash and Snyder (1962). All plates were incubated in a culture room at 23±2°C and under 12 hr of fluorescent light per day for 2 weeks. Isolations from these plates were transferred into culture plates containing water agar medium and an autoclaved carnation leaf; these were microscopically examined for FMS 1 week later. The FMS isolated from these plates were tested for virulence on 1-yr-old slash pines grown in clay pots at the Forest Insect Research Laboratory of the University of Florida. Slits were made with a pre-sterilized scalpel on 2 branches of 4 plants selected. The slit on one of the branches was sprayed with sterile distilled water (control) and the other slit was sprayed with an inoculum similar to the one used in the field. Each slit was covered with a pad of sterile cotton moistened with sterile distilled water. These shoots were observed up to 10 weeks for pitch canker symptoms; shoots dead or dying with disease symptoms were removed, flamed and a chip of the inner stem removed with a pre-sterilized knife was plated in

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[5] Supplied by T. Miller of the USDA Forest Service Southeastern Forest Experiment Station, Olustee, FL

[6] Prepared by S. W. Oak, formerly at the Forest Pathology Laboratory, University of Florida, Gainesville, FL

Nash and Snyder's Fusarium medium. The presence of FMS was confirmed by microscopic examination.

Results and Discussion

Incidence of FMS on G. fuscus Adults Collected from Slash Pines in a Pitch-cankered Plantation

There were several species of fungi growing on the plates with G. fuscus adults. The number of FMS-contaminated G. fuscus adults and paper points found in these plates are shown in Table 4.

Table 4. The number and percent of G. fuscus adults and paper points (controls) contaminated with pitch canker fungus at Norfleet Slash Pine Plantation located in Gilchrist County, FL (November - December 1979).

Item	Contaminated		Non-contaminated		Total
	No.	%	No.	%	
G. fuscus	7	3.9	174	96.1	181
Paper points	9	5.0	172	95.0	181
Total	16	4.4	346	95.6	362

The percent contamination of G. fuscus adults with FMS, 3.9% with binomial confidence intervals of 1-9% at P = 0.99 (Steel and Torrie 1960), was low compared to the 50% contamination of deodar weevils observed by Blakeslee et al. (1978). The number of G. fuscus adults and paper points (controls) contaminated with FMS did not differ significantly (X^2 = 0.26 NS with 1 df and probability of a larger X^2 value = 0.05). These results do not suggest that *G. fuscus* adults are major vectors of pitch canker fungus in this slash pine plantation.

Gnophothrips fuscus Feeding Wounds on Slash Pine Conelets as Infection Courts for FMS

The conelet mortality per treatment and the number of dead conelets from which FMS was re-isolated are shown in Table 5.

Table 5. The initial number and mortality of conelets, and the number of conelets from which *Fusarium moniliforme* var. *subglutinans* (FMS) was re-isolated in an experiment to find whether feeding wounds of *Gnophothrips fuscus* adults can be infection courts to FMS in slash pine clone 74/61 grown at the University of Florida Clonal Pine Bank located in Alachua County, FL (January - May 1980).

Treatment	N	Conelets dead		Dead conelets from which FMS re-isolated	
		No.	%	No.	%
G. fuscus and FMS	48	18	38	1[a]	6
FMS only	44	13	30	2[b]	15
G. fuscus and dist. water	51	6	12	0	0
Dist. water only	48	9	19	0	0

a. Thrips-damaged conelet.

b. One conelet thrips-damaged, other undamaged.

Eight of the 48 conelets exposed to G. fuscus adults and sprayed with FMS inoculum had feeding wounds by thrips. Three of the thrips-damaged conelets died and pitch canker was isolated from 1 of them. There was no thrips damage on the 44 conelets sprayed with FMS inoculum only. Twenty-two of the 51 conelets exposed to G. fuscus and sprayed with distilled water had thrips damage symptoms. Three of these died and FMS was not isolated from any of them. There were no thrips damage symptoms on conelets sprayed with distilled water only.

Among treatments the number of dead conelets from which FMS was isolated did not differ significantly (X^2 = 3.23 NS with 3 df, P = .05). These data do not suggest that G. fuscus feeding wounds serve as infection courts for FMS. Nonetheless there was a significant difference among treatments (X^2 = 11.6 ** with 3 df) in the percent of dead conelets. The mortality was higher (30-38%) among conelets sprayed with FMS compared to those sprayed with sterile distilled water (12-19%). Miller and Bramlett (1978) also reported higher mortality (30-54%) among FMS-sprayed conelets compared to the controls (3-11%). However, they re-isolated the fungus from 64-73% of the dead conelets compared to 6-15% obtained here. It is possible that the technique used in this experiment, i.e. flaming of the conelets, particularly those that became dry in the field, may have killed the fungus. The pollen bags used by

Miller and Bramlett (1978) could have retained more moisture than the sleeve cages used in this experiment and thus may have minimized drying-up of dead conelets collected in their experiment.

Summary

The adults of *Gnophothrips fuscus* collected from slash pines in a pitch-cankered plantation had a low level of contamination with *Fusarium moniliforme* var. *subglutinans* (FMS). This contamination level did not differ significantly from that of the paper points used as controls.

The number of dead conelets from which FMS was re-isolated did not differ significantly among conelets exposed to *G. fuscus* adults and sprayed with an inoculum of FMS, and in controls used. There was significantly higher mortality among slash pine conelets sprayed with the inoculum of FMS compared to those sprayed with distilled water only.

CHAPTER X
INSECTICIDAL CONTROL OF THRIPS DAMAGE TO SLASH PINE CONELETS

Introduction

Thrips injury to slash pine conelets was effectively minimized by spraying a water emulsion of heptachlor either early (as soon as bud scales open) or early and late (shortly before conelets became receptive to pollen) in the development cycle (Ebel 1965). Two mist-blower applications of either heptachlor or malathion reduced thrips attacks on slash pine conelets (DeBarr and Matthews 1971). At present malathion is registered for control of *G. fuscus* in slash pine seed orchards in Florida (EPA 1977). The current recommendation is for 2 applications either by mist-blower or by air-blast sprayer of 1.125% (vol/vol) water emulsion of Fasco malathion liquid-5; the first application to be carried out at the twig-bud stage and the second 1 week prior to maximum pollen receptivity.

Insecticidal Treatment of the Bark

Introduction

The results of a previous study on seasonal abundance (see page 57) suggested that *G. fuscus* adults apparently overwintered on and fed upon the conelets of the same slash pine. Some pine-inhabiting thrips are known to overwinter under the bark (Lewis and Navas 1962). Gnophothrips fuscus adults were once collected from the bark of young slash pines (see page 33) during winter. The objective of this study was to investigate the possibility of reducing G. fuscus damage to conelets by spraying an insecticide in early winter onto the bark of slash pines in a seed orchard.

Materials and Methods

This study was conducted from December 1978 through May 1979 at McColskey Still Seed Orchard (see page 63 for details). Five slash pine clones grown in this orchard were selected on the basis of their female strobili bearing capacity (C. W. Fatzinger, personal communication, 1978). Four randomly chosen ramets per clone were assigned for the insecticidal spray and 4 others were used as untreated controls. Two sticky traps (see page 53 for details) were hung in the southeast quadrant of each ramet to monitor G. fuscus population flying within the crown. These traps were replaced monthly and the number of thrips caught were recorded. In early winter (December 21-22) a water emulsion of 0.125% lindane (by weight) was applied to the point of run-off, onto the bark of the trunk and the branches in the upper half of the crown of the ramets to be sprayed. A commercial hydraulic sprayer operating at a pressure of 17.58 kg per cm^2 (250 lbs per $inch^2$) was used. This sprayer was equipped with a system to continuously agitate and mix the emulsion.

Lindane was selected because of its long residual life (6 weeks when applied with water) and its effectiveness in controlling some bark insects (Lyon 1965). Only 13 ramets were sprayed on December 21 due to 16 km per hr wind and a light rain in the afternoon. The remaining ramets were sprayed on the following day. In January 1979 the upper southeast quadrant was demarcated at the mid-crown of the ramets by using yellow plastic flaggings. This quadrant was chosen because it has a higher percent of female strobili (DeBarr *et al*. 1975). Beginning on the 4th week of January 25 clusters of conelets were tagged as they became discernible in the southeast quadrant of the ramet. The location, number and initial condition of the conelets were recorded. These strobili were observed again in February-March and April-May to determine if thrips damage has occurred. These data were recorded on data sheets used in cone and seed insect research at the USDA Forest Service Southeastern Forest Experiment Station at Olustee, FL. The data were summarized to find the number of thrips-killed conelets. Before the analysis the data were transformed into the arc sin of $\sqrt{\text{percent of thrips-killed conelets}}$.

Results and Discussion

Between February and May there was significantly less (F = 12.17** with 1 and 30 df) conelet mortality due to *G. fuscus* damage in the sprayed (vs. unsprayed) ramets. Further analysis showed that conelet mortality was significantly reduced only in ramets belonging to clones 1, 3 and

and 5 only (Table 6). The reasons for this differential response of slash pine clones are not known.

Although this experiment demonstrated the possibility of using an early winter spray of an insecticide onto the bark of slash pines to reduce *G. fuscus* damage to slash pine conelets, in practice it was difficult to confine the spray to the bark. There was some drift of the insecticidal spray onto the shoots and this probably resulted in thrips mortality because later studies indicated that *G. fuscus* overwintered principally on the shoots in the upper crown of mature slash pines.

During April-May more thrips were trapped on the sticky traps hung within the crowns of sprayed ramets (vs. unsprayed ramets) (Table 7). Possibly these trees became more suitable for *G. fuscus* because lindane killed the natural enemies of this insect. Infact, *Leptothrips pini* considered predatory by O'Neill (1965) is invariably found under the bark of slash pines. Thus spraying of an insecticide onto the bark may be detrimental to the long term control of *G. fuscus* on slash pines in seed orchards.

Interaction Between Early Vs. Late Winter Spraying of an Insecticide and Early Vs. Late Flowering in Slash Pine

Introduction

Thrips attacks occur for about a month while slash pine conelets are still succulent (Ebel 1965). Most of the thrips

Table 6. Mortality of *Gnophothrips fuscus*-damaged conelets in ramets with lindane-sprayed bark and in unsprayed ramets belonging to 5 slash pine clones growing at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL (January - May 1979).

Clone no.	Percent mortality of conelets[a]	
	Sprayed ramets	Unsprayed ramets
1	12.7	24.6*[b]
2	11.4	26.1*
3	15.5	18.1
5	15.8	39.6*
6	15.6	23.8
All clones	14.2	26.6**

a. As a percent of the initial number of conelets observed on 100 clusters in 4 ramets per clone.

b. The significance of differences between treatment means was tested using analysis of variance (* P = 0.05, ** P = 0.01). Prior to these analyses the data were transformed into arc sin of the $\sqrt{\text{proportion of conelets killed by thrips}}$; the percentages listed in the Table are not transformed.

Table 7. Number of Gnophothrips fuscus adults caught on sticky traps hung in the upper southeast quadrant of ramets with lindane-sprayed bark and in unsprayed ramets belonging to 5 slash pine clones grown at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL (December 1978 - May 1979).

Clone no.	Month of observation									
	Dec/Jan		Jan/Feb		Feb/Mar		Mar/Apr		Apr/May	
	S	US	S	US	S	US	S	US	S	US
1	3	9	1	3	1	1	2	3	46	11
2	6	11	3	0	4	2	7	3	33	25
3	4	5	1	0	2	1	2	3	17	5
5	3	4	0	3	0	2	0	6	13	13
6	8	8	2	0	2	0	4	1	42	7
Total	24	37	7	6	9	6	15	16	151	61

Note: Each observation is the total catch on 8 sticky traps. Four ramets per treatment and 2 traps per ramet were used. Both Gnophothrips fuscus and Leptothrips pini trapped; number of G. fuscus determined by taking a subsample. (S, sprayed; US, unsprayed).

injury occurs during early stages prior to pollination (DeBarr 1969). Conelets gradually harden after pollination and no longer are fed upon by thrips. Due to clonal variation of flowering in slash pine conelets in an early-flowering clone may become receptive to pollen ca. 3 weeks prior to those in a late-flowering clone (Rockwood 1978). Thus conelets in an early flowering clone cease to be fed upon by thrips ca. 3 weeks before those in a late-flowering clone. These differences in flowering phenology can affect the timing of insecticidal sprays to control _G_. _fuscus_ on slash pine (Ebel 1965). This investigation was undertaken to determine whether there is interaction between early vs. late flowering in slash pine clones and early vs. late winter insecticide applications to control _G_. _fuscus_ damage to conelets.

Materials and Methods

This study was conducted from December 1979 through May 1980 at McColskey Still Seed Orchard. Twelve ramets from 2 early-flowering clones (numbers 1 and 3) and 2 late-flowering clones (numbers 4 and 6) were selected for this study. Four randomly chosen ramets per clone were assigned to the following treatments:

(1) Unsprayed (controls)

(2) Early spray of malathion

(3) Late spray of malathion

Malathion was selected because it is currently registered for _G_. _fuscus_ control in slash pine seed orchards in Florida (EPA 1977). Using a hydraulic sprayer operating at

17.58 kg per cm^2 (250 lbs per $inch^2$), 0.75% water emulsion of malathion was sprayed to the point of run off (ca. 38 liters per tree) to the foliage of the ramets so assigned. This sprayer was equipped with a system to continuously mix and agitate the insecticide emulsion. The early spray was carried out on December 26 and the late spray on January 29. The upper southeast quadrant of each ramet was demarcated at the mid-crown by using 2 yellow flaggings each hung on a branch along the south and east compass bearings. Twenty-five clusters of conelets per ramet were tagged from this quadrant as they became visible from late December through January. The top conelet of each cluster was marked with a piece of colored wire and the other conelets were numbered relative to it. The initial condition and the number of conelets per cluster were recorded. These conelets were observed again during February-March and April-May to detect the occurrence of thrips damage symptoms. The data were recorded in "new" data sheets used in cone and seed insect research at the USDA Forest Service Southeastern Forest Experiment Station at Olustee, FL. These data were transformed into arc sin $\sqrt{\text{fraction of thrips-killed conelets}}$ before the analysis of variance[1].

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[1] Done by H. Bhattachcharyya of the USDA Forest Service, Research Triangle Park, NC

Results and Discussion

The percent of thrips-damaged and thrips-killed conelets per treatment are shown in Table 8. The analysis of the transformed data showed no significant interaction (F = 0.88 NS with 6 and 36 df and probability of a larger F = 0.05) between the clones and treatments. This lack of interaction may be due to the different rates of development of conelets among the slash pine clones, e.g. although female strobili buds of clone number 3 were visible earlier than those in clone number 4, the conelets in the latter clone opened before those of the former clone. Overall there was significantly less conelet mortality due to thrips damage in the sprayed ramets (vs. unsprayed ramets). However, analysis using orthogonal contrast procedure indicated no significant difference (F = 2.06 NS with 1 and 36 df and probability of a larger F = 0.05) in the number of thrips-killed conelets between ramets receiving early vs. late winter spray of malathion.

Summary

An early winter spray of lindane to the bark of slash pines significantly reduced thrips damage to conelets. But such a spray may also kill the natural enemies of *G. fuscus* and can be detrimental in the long term.

There was no significant interaction between early vs. late winter spray of malathion to control *G. fuscus* damage to slash pine conelets and early vs. late flowering of slash pine clones in a seed orchard.

Table 8. The percent of Gnophothrips fuscus-damaged and G. fuscus-killed conelets in malathion-sprayed ramets and in unsprayed controls belonging to 2 early-flowering and 2 late-flowering slash pine clones growing at the USDA Forest Service McColskey Still Seed Orchard located near Lake City in Columbia County, FL (January - May 1980).

Clone no.	Treatments					
	Unsprayed		Early spray		Late spray	
	Damaged	Dead	Damaged	Dead	Damaged	Dead
1[a]	17.62	3.57	2.57	0.00	0.42	0.39
3[a]	12.79	6.38	7.25	1.67	1.44	0.00
4[b]	15.24	4.25	3.62	0.00	4.28	0.00
6[b]	12.96	1.70	12.98	4.30	17.04	0.00

Note: Based on conelets in 100 clusters per observation; 25 clusters x 4 ramets per treatment.

a. An early-flowering clone. Flowering was assumed to have begun when an accumulative 50% of the female strobili buds in 10 clusters and in a minimum of 3 branches in the upper crown were completely visible.

b. A late-flowering clone. Flowering began at least 2 weeks after an early-flowering clone.

CHAPTER XI
SUMMARY AND CONCLUSIONS

The bionomics of the slash pine flower thrips, _Gnophothrips fuscus_ (Morgan), was studied from December 1977 through June 1980 on slash pines growing in northeastern Florida.

Gnophothrips fuscus adults collected during this investigation were polymorphic and had a male: female sex ratio of 1: 3. The mating behavior of this thrips was similar to that reported in the literature on other phlaeothripids.

This thrips was reared in the laboratory from egg to adult in ca. 46 days at 22±1°C and 12L:12D photoperiod. The immature stages of this insect are described here for the first time. The sculptured chorion of the egg is perforated apparently with openings resembling aeropyles. This sculpturing may be diagnostic for the species. The other immature stages can be distinguished by the structure of their antennae and chaetotaxy.

During spring and summer all the life stages of _G. fuscus_ were collected from the current vegetative growth of young slash pines. This observation suggests the need for an investigation on the possibility of reducing _G. fuscus_ populations by either removing or spraying young slash pines in and around slash pine seed orchards. It is also worthwhile to study the impact due to isolation strips and barriers of hardwoods around the seed orchards on _G. fuscus_ populations. In this regard it is necessary to know the dispersion range and pattern of _G. fuscus_ from its breeding places. The occurrence of _G. fuscus_ immature stages on the current vegetative growth indicates the need to study the relationship between the use of nitrogen fertilizer and _G. fuscus_ populations in slash pine seed orchards. The possibility of using a mixture of an ovicide and a wetting agent to destroy thrips eggs during early spring should be studied.

The relative abundance of _G. fuscus_ life stages on young slash pines is illustrated. An estimated 3 generations occur on these pines during spring and summer. Once the eggs and larvae of this insect were observed on the conelets of slash pines in a seed production area. Further study on the presence of _G. fuscus_ immature stages on the conelets is necessary.

The number of _G. fuscus_ adults caught on sticky traps hung at the upper crowns of 6 cone-bearing slash pines was lowest during winter, reached a peak during spring and gradually declined through summer and fall. This low flight activity during winter suggests that _G. fuscus_ adults feeding on the conelets of a given slash pine most likely also overwintered on the same tree. This implies the possibility of using a systemic insecticide early in the winter to control thrips damage to conelets in slash pine seed orchards.

More _G. fuscus_ adults were trapped at mid- and upper crown of cone-bearing slash pines than at lower crown and bole levels.

Slash pine flower thrips damage to growing needles appeared as yellowish-white patches. This damage apparently does not affect the vegetative growth seriously enough to warrant control measures. Thrips damage to sporophylls resulted in the degeneration of the mesophyll. In those conelets which died with thrips damage symptoms ca. 7% of the sporophylls were thrips-attacked.

Incidence of pitch canker fungus was low on G. fuscus adults collected from slash pines (and did not differ significantly from the incidence of the fungus on paper points used as controls) in a pitch-cankered plantation. Thrips feeding wounds on slash pine conelets did not appear to be infection courts for this fungus. Although these data show that G. fuscus is not a major vector of this fungus further studies on all the life stages of this insect collected at different times of the year are necessary. These thrips may be observed under a scanning electron microscope to detect the presence of fungal spores on their bodies.

Although a lindane spray onto the bark of slash pines significantly reduced G. fuscus damage to conelets, this practice may be detrimental due to its possible effect on the natural enemies of this thrips. With reference to the number of thrips-killed conelets, there was no significant interaction betweeen the timing (early vs. late winter) of a malathion spray and chronology (early va. late) of flowering of 4 slash pine clones in a seed orchard.

APPENDIX A
DEVELOPMENTAL STAGES OF PINE FEMALE STROBILI FROM BUD-BREAK TO POLLINATION

Slash pine (Rockwood 1978)	Southern pines (Bramlett and Gwynn 1980)
Stage I: Whitish bud scales visible and strobili buds identifiable.	Stage 1: Female strobilus bud small and tightly enclosed in bud scales.
Late Stage I: Whitish bud scales prominent and bud begins to open.	Stage 2: Bud enlarged but primordia still enclosed in bud scales. Light-colored scales noticeable at the tip of the bud.
Early Stage II: Purple conelet scales begin to appear.	Stage 3: Conelet begins to emerge.
Late Stage II; Purple conelet scales well visible but closed.	Stage 4: Conelet elongated ca. 2/3 extended beyond bud scales. Conelet scales closed.

Early Stage III: Pinkish conelet scales begin to open.	Late Stage 4: Conelet almost completely out of bud scales. Conelet scales still partially closed.
Stage III: Conelet scales pink, open at right angles to the axis.	Stage 5: Conelet completely out of bud scales. Bud scales rolled back. Conelet scales at right angles to the axis.
Late Stage III: Conelet scales pink, beginning to close.	Late Stage 5: Conelet scales gradually increase in size and beginning to close.
Stage IV: Conelet scales gradually become light green, swell and close.	Stage 6: Conelet scales completely closed.

APPENDIX B
PROCEDURE TO PREPARE SLASH PINE FEMALE SPOROPHYLLS FOR SECTIONING

Step no.	Reagent used		Duration
	Components	Ratio	
1.	Water: Abs. EtOH	1: 1	2 hr
2.	Water: 95% EtOH: 100% TBA	5: 4: 1	2 hr
3.	Water: 95% EtOH: 100% TBA	3: 5: 2	Overnight
4.	Water: 95% EtOH: 100% TBA	3:10: 7	2 hr
5.	95% EtOH: 100% TBA	9:11	2 hr
6.	100% TBA: Abs. EtOH	3: 1	2 hr
7.	Abs. EtOH	----	1 hr
8.	Abs. EtOH	----	Overnight
9.	Abs. EtOH	----	2 hr
10.	TBA/Paraffin oil	1: 1	2 hr or until sinks
11.	Paraffin oil/Wax (61°C)	1: 1	2 hr
12.	Wax (61°C)/Paraffin oil	3: 1	2.5 hr or until sinks
13.	Wax (61°C)	----	2 hr
14.	Wax (61°C)	----	Overnight

15. Wax (61°C)	----	2 hr

16. Embed in wax (61°C) in aluminum trays, cool until hard, refrigerate overnight, trim and mount.

Source: T. W. Lucansky of the Department of Botany, University of Florida, Gainesville, FL (Abs. EtOH, absolute ethyl alcohol; EtOH, ethyl alcohol; TBA, tertiary butyl alcohol).

APPENDIX C
SAFRANIN-FAST GREEN STAINING SERIES

Step no.	Reagent Used	Duration
1.	Xylene	10 min
2.	Xylene	10 min
3.	Xylene	10 min
4.	Absolute EtOH	5-10 min
5.	Absolute EtOH	5-10 min
6.	95% EtOH	5-10 min
7.	85% EtOH	5-10 min
8.	70% EtOH	5 min
9.	50% EtOH	5 min
10.	Safranin (1% in 50% EtOH)	Overnight
11.	Distilled water	Until no red color comes out
12.	50% EtOH	3-5 min
13.	70% EtOH	2-5 min
14.	85% EtOH	2-5 min
15.	Fast Green (1% in 90% EtOH)	10-120 sec
16.	90% EtOH	In and out twice

17.	Absolute EtOH	In and out twice
18.	Xylene	5 min
19.	Xylene	5 min
20.	Xylene	5 min

Source: T. W. Lucansky of the Department of Botany, University of Florida, Gainesville, FL. (EtOH, ethyl alcohol).

APPENDIX D
DERIVATION OF THE STATISTICAL MODEL

The reduced model was derived from a saturated model which accounted for all the sources of variation. The saturated model was:

$$\mathrm{Ln}\left(\frac{N_n}{N_y}\right) = \mu + Y_i + S_j + S(Y)_{(i)j} + L_k + YL_{ik} + LS(Y)_{(i)jk}$$

where:

Ln = natural logarithm,

N_n = number of traps without a catch,

N_y = number of traps with a catch,

μ = mean,

Y_i = year effect,

S_j = season effect,

$S(Y)_{(i)j}$ = season x year interaction,

L_k = quadrant effect,

YL_{ik} = year x quadrant interaction,

$LS(Y)_{(i)jk}$ = season x year x quadrant interaction.

A chi-square test was performed to determine if there was evidence of lack of fit of the reduced model. This was done by using the formula:

$$X^2 = \frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}}$$

where: Observed = observed number of traps with thrips,

and Expected = number of traps expected to have a catch. This was calculated by using the formula:

$$\text{Expected} = \frac{\sqrt{18 \times N_y}}{N_y + N_n}$$

because there were 18 traps, i.e. 6 trees and 3 months, / quadrant / season.

At 95% confidence interval $X^2 = 20.07$ (NS with 24 df) i.e. no significant lack of fit in the reduced model used.

Source: R. Lynch of the IFAS Statistical Unit, University of Florida, Ganiesville, FL

APPENDIX E
SELECTIVE MEDIUM FOR *Fusarium moniliforme* var. *subglutinans*

Ingredients:
1. 200 g fresh potatoes
2. 20 g agar
3. 20 g dextrose
4. 1 liter distilled water
5. 1 g Demosan
6. 1 g PCNB
7. 0.3 g Streptomycin Sulfate
8. 0.1 g Neomycin Sulfate

Method: Boil the potatoes, strain through a cheese-cloth. Add agar and dextrose, sterilize at 1.05 kg per cm^2 (15 lbs per $inch^2$) for 30 minutes. Cool to 40°C. Add remaining ingredients and dissolve.

Note: This medium is a modification by Jane Barrows at the USDA Forest Service, Forestry Sciences Laboratory in Athens, GA and was originally published by Agrawal *et al*. (1973).

Source: T. Miller of the USDA Forest Service Southeastern Forest Experiment Station, Olustee, FL

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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